DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

Technical Report 1689-TR

PROTECTIVE CONSTRUCTION BY PROVED COMPONENTS

Project 8S12-95-001

21 August 1961

U. S. Army
Engineer Research And
Development Laboratories

FORT BELVOIR, VIRGINIA

U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES
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PREFACE

The principal work performed by the U. S. Army Engineer Research and Development Laboratories directly in behalf of this study was in conjunction with consultant work for The Engineer School in preparation of Technical Manual 5-311, Engineer Troop Protective Construction. It is anticipated that publication of the technical manual will include much of the material in this report and will present data for determination of radiological protection, as well as designs for utilization of existing structures, tunnels, and fortifications. Some of the work included in this technical report, notably the timber structures and components and the massive entrance sections, are not to be included in the technical manual. In addition, some of the development and theory presented in this report in the selection of the structures and structural components is not to be in the technical manual.

Personnel assisting in the preparation of the work for the technical manual and, consequently, in the development of the system as presented in this technical report were Captain Clifford T. Flanagan of The Engineer School and SP/4 Arthur N. Stacy of Special Projects Branch, USAERDL. The principal weapons test data used in the theoretical or empirical development of the system were derived from work of the Naval Civil Engineering Laboratory, Port Hueneme, California; the Office of Civil and Defense Mobilization, Battle Creek, Michigan; the Air Force Special Weapons Center, Sandia Base, New Mexico; the Waterways Experiment Station, Vicksburg, Mississippi; and the USAERDL. Data furnished by the Signal and Chemical Corps, as well as the Corps of Engineers, were also used in the selection of utility components.

Although much of the work presented here is to appear in TM 5-311, this report is published to present extensions of designs and uses of materials of construction which were not included in the technical manual.

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CONTENTS (cont'd)

SUMMARY

~~This report presents~~ a system for protective construction by use of proved components. ~~The report covers~~ the development of concepts of design, actual designs and tables for material selections, and schemes for use of proved utilities together with requirements for such utilities based on structure utilization. The system of design is based on results of past nuclear weapons tests, high explosive tests, and nondestructive test programs.

The system of design is presented in such a manner that a field engineer may start with the requirements placed upon him for a protective structure; examine tables of utilities based on structure utilization; examine basic structures, as well as structural components, and adapt to these the material and labor forces available for construction. The system is designed to free the field engineer from the restrictions which would be imposed by presenting only prototype structures and yet to provide him with structural designs which have proved resistant to nuclear blast effects. A wide variety of materials and shapes of structure is presented. The simplest of these can be constructed with unskilled labor under competent direction, although more advanced shapes and complicated "form work" are required for some of the other structures.

The more important results of this study of a system of protective construction are the presentation of structural shapes which may be readily assembled and easily transported and yet fulfill, to the highest degree, the blast protection required; and the assembling of the variety of blast resistant components from the multitude of weapons test data and reports.

~~The report concludes that~~: (a) Results of nuclear weapons effects tests are of sufficient scope and quality that a system of field protective construction by the use of proved structural and utility components is feasible; (b) the system of design by proved components presented here allows a field engineer not trained in nuclear weapons effects to apply the results of nuclear tests to satisfy the requirements placed upon him for protective structures; and (c) protective structures may be designed as an assembly of independent components reacting to blast or shock loadings in such a manner that the reaction of one does not weaken the resistance of another.

ILLUSTRATIONS

TABLES

PROTECTIVE CONSTRUCTION BY PROVED COMPONENTS

I. INTRODUCTION

1. Objectives. The objectives of this study were:

a. To provide the field engineer with a system of construction or prototype structures which would have proved blast resistance as determined from nuclear weapons effects testing.

b. To consolidate and evaluate the test results of past test programs or the incidental results of such testing. Furthermore, the purpose was to present such data in a readily usable form so that the proved results could be applied by the field military engineer.

c. To extrapolate past nuclear test results to allow field protective construction in which a variety of available materials or prefabricated shapes and a range of structure types is used.

2. Background. Test programs incidental to weapons development and weapons effects tests were conducted until 1958. During this period, a great number of prototype structures and some "pure" structural shapes were tested. Some of these test programs were on elaborate prototype structures in which some positive and some negative results were obtained on various facets or components. In the past, these test results have been used to evaluate such prototype structures. The nuclear weapons test moratorium initiated in November 1958 precluded the testing of new prototype structures which were developed as a result of the past tests.

The field military engineer is likely to be presented with structure requirements of a wide variety. He may have on hand only a minimal choice of building materials to satisfy these needs. In addition, the further limitations of labor force, construction materials, or equipment may prevent the utilization of certain of these building materials. To present the field engineer with a few detailed prototype structures but with no other provisions for adapting or modifying such structures is likely to create the condition where no structure will be built. It should be assumed that the field military engineer can adapt and modify structural design to suit his needs when he is provided the criteria under which such designs were based; the critical features of blast protection or blast effects against which such designs were created to protect; and the limitations of the structural designs presented. When these assumptions are made and when the wealth of available data incidental to or directly derived from the nuclear blast effects tests are considered, it would seem reasonable that a system of blast resistant designs could be provided the field engineer so that structures for which no prototype tests have been made could be built in the field.

Current Army technical manuals present the field engineer with prototype structures for blast resistance or other requirements. Occasionally, specific modifications to these structures are submitted with the designs. Almost without exception, no alternatives are presented by which the engineer can readily adapt these designs to suit specific requirements or limitations of construction material, labor, or equipment. Great planning and logistic advantages exist in using such a design program, in that, material and troop construction may be accurately predicted. Further, materials utilizing such designs are standardized (for example, 2 by 4 lumber or corrugated roofing) and, thereby, may be readily used for other jobs should the need arise. The qualities of prototype structures which have been developed have been such that their components are unique or that the methods of construction required (for example, arched reinforced concrete), necessitate skilled labor for their erection. Therefore, it would be of apparent value should material providing a high degree of nuclear blast protection be readily adaptable to many jobs. Such material would likely be available in the theater army for these varied purposes.

3. Theory. Specific structural theory for the development of the designs presented in this report is given elsewhere. The fundamental concept upon which the system of design by components is based is that tests have been run on such a variety of structural shapes and materials that structural components may be selected so that each component will exhibit adequate resistance to nuclear blast effects. It is further assumed that these components may be assembled into a structure so that each component will fulfill the requirement for resistance placed upon it without weakening the remainder of the structure. The basis for assembling the structural components is to select their design and placement so that each component and the structure itself act independently of any other component. Thus, the entrance configuration is not structurally attached to the basic structure or its end wall and, within itself, may be of independently acting parts. Similarly, the other components such as the floor, the basic structure, the end wall, the entrance doorway, and the entrance frame are constructed in such a way that they act independently to secure their full resistance to blast effects without transferring loads or weakening the resistance of the other components.

Wherever possible, the specific designs have been cross-checked by separate theoretical and empirical approaches; for example, the theoretical strength of a member has been checked against the bracketed absolute strength exhibited under nuclear test conditions. Static, dynamic, nuclear, high explosive, and nondestructive test results have all been employed to define the response and the strength of the components employed in the structural design system.

II. CRITERIA FOR DESIGN

4. Types of Dynamic Loading. Structural design for nuclear blast requires consideration of rapid, transient, and lateral loads different from those used for conventional design. Overpressures which never appear in civil design must be considered. Where conventional construction may dictate only 4 psi (for example, for a warehouse floor), structures to provide for the effects of nuclear blast can be designed for 10, 100, or 1,000 psi. In addition, little correlation exists between nuclear blast resistant design and that for the effects of conventional weapons such as aerial bombs or artillery projectiles. Structures for conventional warfare are principally concerned with penetration of a projectile or its fragments and with the shattering effects of the high explosive. In contrast, nuclear weapons have no shattering effect, fragmentation or penetration.

High explosive (HE) detonations may develop extremely high overpressures, but the pressures are localized and of short duration when compared with the other effects of fragmentation and shattering. However, overpressure is the principal effect of a nuclear detonation upon a structure. The overpressure will suddenly rise to a peak and then will decay in such a manner that the entire structure will be loaded for a finite time. The structure must be able to withstand this overpressure. The distance of the structure from the detonation, the depth of burial, and the size of the weapon yield may cause the overpressure to decay rapidly or slowly in relation to the response time of the structure. The overpressure may be magnified by reflection from the earth's surface. As the blast wave travels across the ground at a high velocity large reflected pressures may be developed when it interacts with a surface in its path. The magnitude of amplification is dependent on the peak side-on overpressure and the angle of incidence of the direction of travel to the surface. Figure 1 shows these relationships.

When the blast wave is reflected, channelized, or strikes an interior corner it may be magnified many times. In addition, the actual mass of the air in the blast front and in the following compressed air has a velocity which causes a drag when the blast wave envelops and passes around aboveground structural elements.

The development of large negative overpressure, an additional feature of nuclear blast which is negligible in HE detonations, is seldom considered in civil practice. The negative pressures may be on the order of 5 psi below atmospheric; consequently,

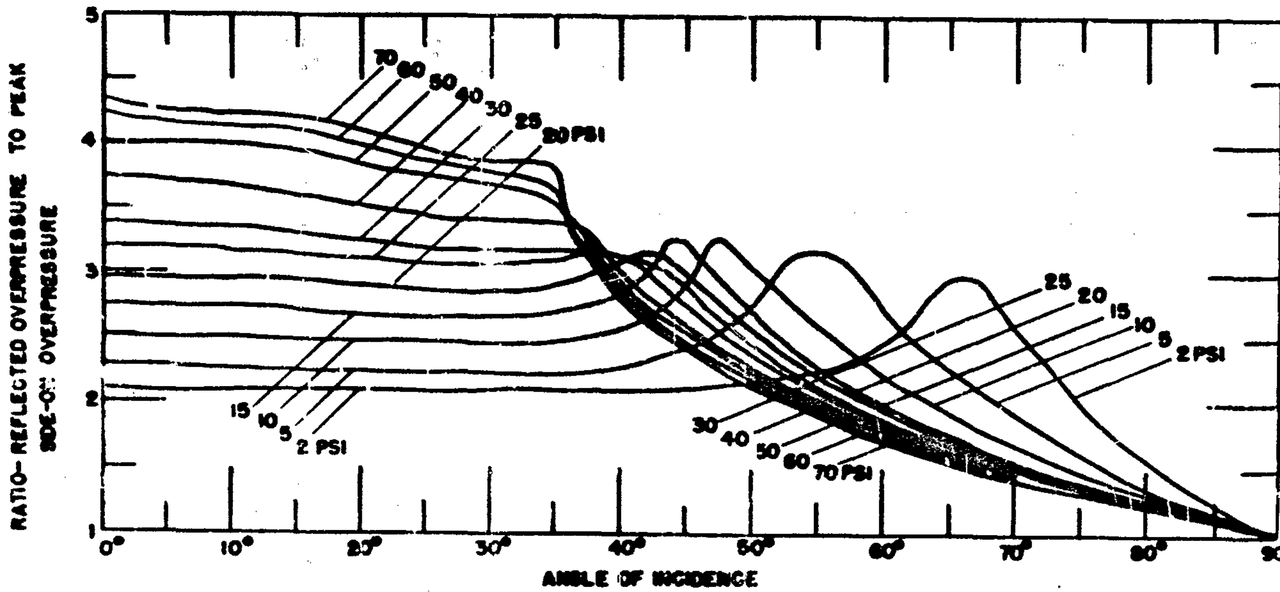
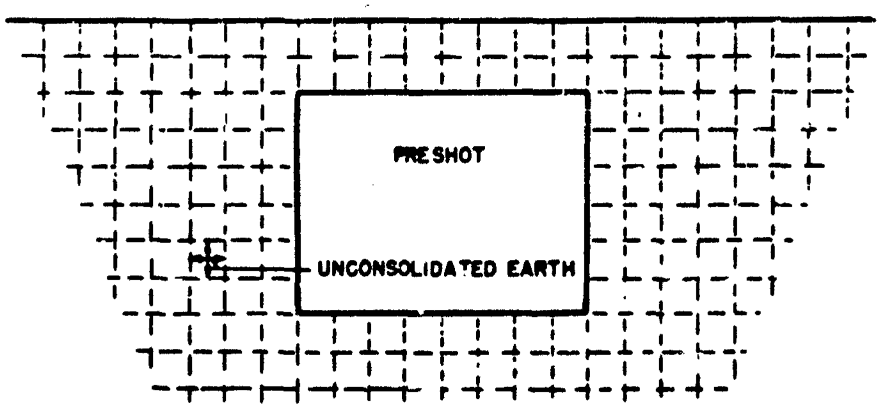


Fig. 1. Relation of reflected pressure to side-on overpressure and angle of incidence.

the structure experiences an outward load because of the static pressure of the air it contains. These negative pressures have been the principal cause of destruction of tactical emplacements. Such negative pressures may provide an additional damaging effect on aboveground or near-surface structures and, therefore, must be considered in protective structure design. The drag effects and the large increase in overpressure developed by reflection from an aboveground structure hinder the use of such construction for blast protection. Similarly, other effects which would prohibit aboveground construction are the low initial and fallout radiation protection provided by such structures.

A semiburied structure employing a raised earth embankment may have large reflected pressures developed on the sides of the berm which are transmitted to the structure. A semiburied structure is defined here as one completely covered but with the earth covering raised above the surface. Placement of a structure in the fully buried condition in which the earth over the structure is flush with the surrounding surface eliminates the need for consideration of reflected and drag pressures. The requirement for consideration of negative pressures depends upon the depth of burial and type of structure. It is assumed that a negative pressure on the order of 4 psi or less is the maximum that would be encountered under most conditions. To develop a damaging upward force within the structure a net negative pressure of at least ½ psi would probably be required. An overburden of 4 feet or more earth cover would be sufficient to eliminate the possibility of such an upward force. Entrance configurations, which must come to the surface, are not likely to bring a net upward force to bear on the structure of the passageway. The entrance closure and its foundation, however, must be designed for the possible effects of negative overpressure in the passing blast wave.

Nuclear tests have indicated that a considerable reduction in overpressure occurs in the first two to three feet below ground surface. This reduction may be on the order of one-third the peak sideon overpressure. Further reduction with a depth below this first increment is extremely small, however, and may be assumed to be negligible through the region in which buried structures with minimum earth cover are located. High overpressures may be developed both on the roof and sides of a buried structure. The magnitude of the pressures on the side are related to the compaction and the earth fill. The response of this earth fill becomes extremely important; if it consolidates to any degree under the blast pressure, additional loads upon the structure may be created by arching from the structure to the adjacent soil. With arch structures themselves, a large consolidation of the soil adjacent to the structure may create high tangential friction forces on the structure. These effects are illustrated in Figs. 2 and 3. In some nuclear tests, this force has been sufficient to bring about the failure of the structure.



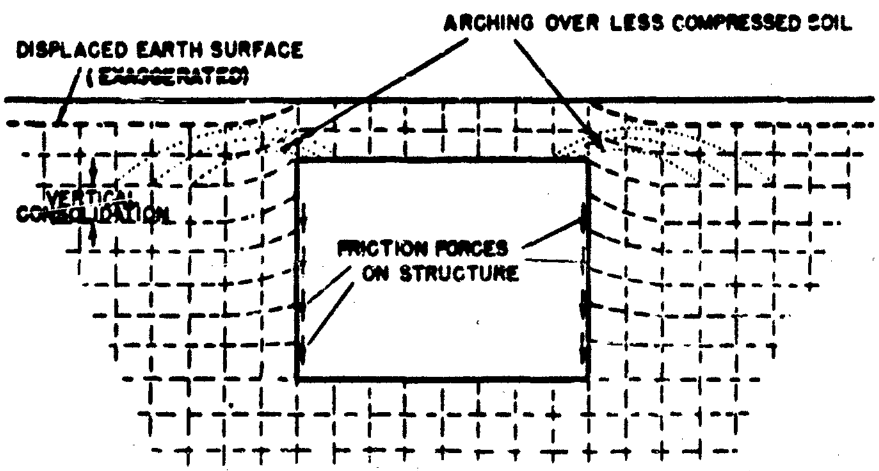


Fig. 2. Arching action developed by soil consolidation. The soil immediately adjacent to the structure does not consolidate as much as that in the free field, further from the structure. The result is that vertical loading about the periphery of the structure is partially borne by arching action by the structure and the consolidated soil away from the structure.

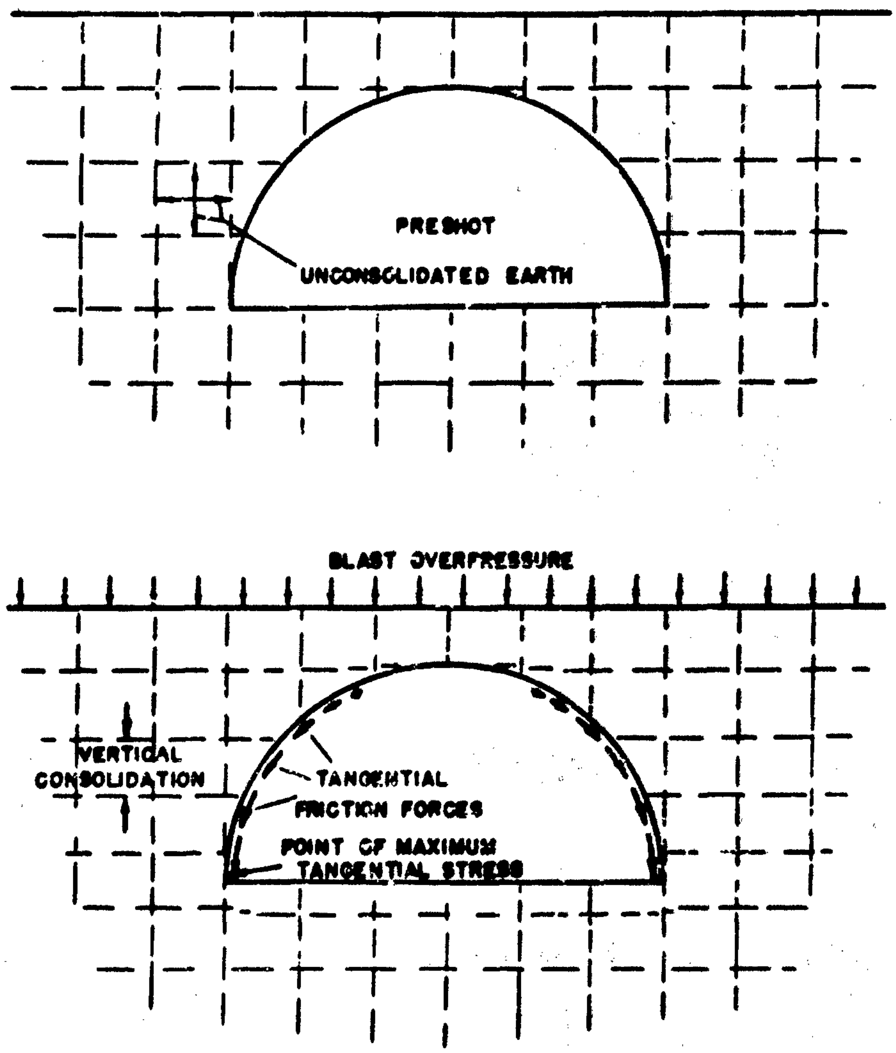


Fig. 3. Development of tangential friction forces on an arch structure by soil consolidation. Consolidation of the soil adjacent to the structure causes a relative movement between the soil and the structure surface resulting in tangential compressive stresses caused by friction.

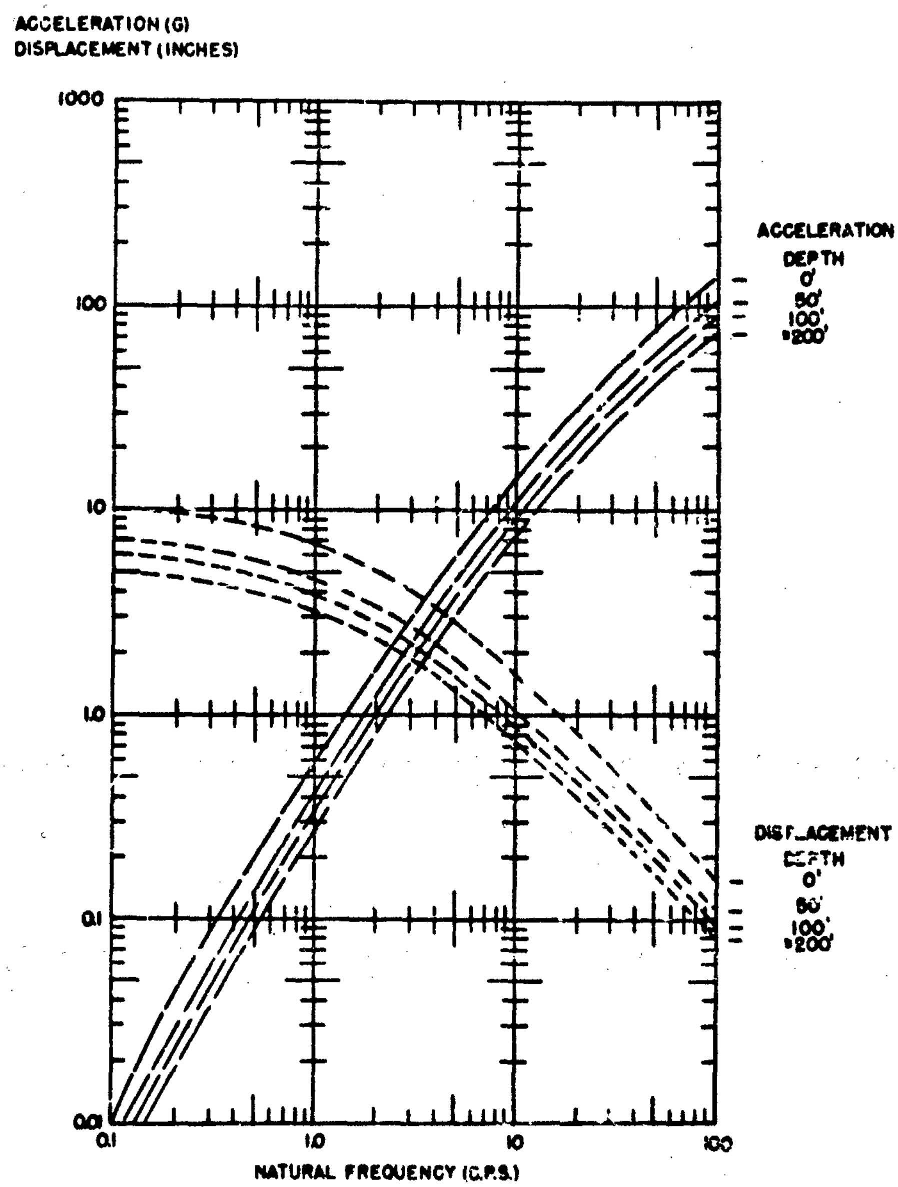


Fig. 4. Typical free-field ground shock spectra.

Nuclear blast effects other than the air overpressure are the rapid transmission of shock through earth and, in particular, through denser mediums such as rock and saturated soil. These pressures may be air induced or directly transmitted from surface or below-surface detonations. The transmission of shock through rock and saturated soil requires that protective structures be isolated from these denser mediums by placement above the water table and by isolation from bedrock. The ground shocks are characterized by high uniaxial pressures. Similarly, varying accelerations are developed in different directions relative to the path of the shock. Typical free-field ground shock spectra are shown in Fig. 4.

5. Structural Response to Static and Dynamic Loads. Conventional structural design is primarily concerned with the problem of transferring known or predicted gravity loads to the earth from some position in space, by a system of structural members, without exceeding allowable stresses. Blast resistant design must provide strength to resist forces normal to structural surfaces, gravity loads, frictional loads caused by settlement of earth fill, and even upward loads acting upon the foundations or floors of the structure. The

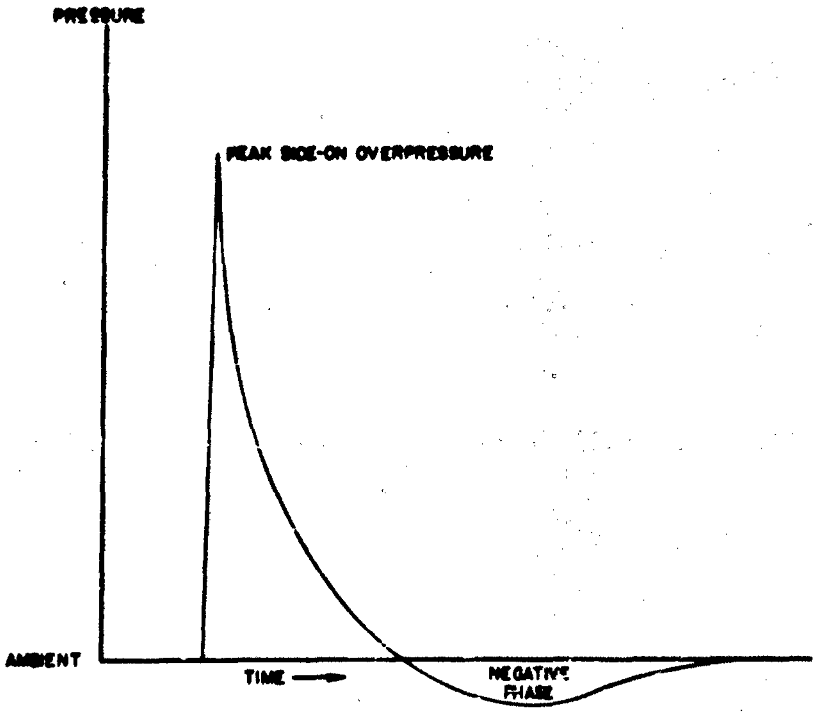


Fig. 5. Idealized air blast overpressure curve.

blast loads from a nuclear explosion are characterized by a sudden rise in pressure, a gradual decay, and a negative pressure of possibly longer duration. An idealized air blast overpressure curve is illustrated in Fig. 5.

The rapidity with which the loads are applied and the type of response of the structure are such that structures must be designed to withstand both the externally applied loads and the momentum developed in the structural elements themselves. As a corollary, the spring of a scale must be able not only to support the weight of the scale and its contents, but must overcome the dynamic loading which results when the mass is applied and the system seeks equilibrium. Similarly, the strength necessary for a roof to resist the overpressure as applied by the blast and the weight of the roof itself must be considered. Also, the loads created by the mass of the roof system having been accelerated under the force of the overpressure consequently require deceleration. Deceleration requires a strength of possibly the same magnitude as that needed to resist the overpressure itself. The duration of the positive pressure of the blast wave, therefore, becomes a critical factor in determining the maximum load which a structure must withstand. This duration is compared to the time of the elastic response of the structure and the magnitude of the elastic response of the structural members in relation to their elastic yield point. Structural elements required for underground structures are of such a stiffness that the time of elastic response of these elements (that is, their natural period of vibration) is short. Thus, the positive pressure phase of a nuclear detonation of any size weapon, 1 KT and larger, is of such a length that it can be considered of infinite duration without significant error. Figures 6 and 7 illustrate these effects. The figures are dimensionless in that the displacements shown in each figure are related to a single line which represents the displacement under a specified load. The rise time of the peak overpressure for such structures, however, is so short that a magnification occurs in the response of the structure. The response is greater than it would have been had the same overpressure been gradually applied over a long period of time.

The structural response to the application of the overpressure becomes important criteria, not only in the determination of the structural strength requirements, but in the selection of the material for construction. For example, a concrete structure in an arch shape may be such that its critical response (that at which failure is most likely to occur) takes place when the structure is rebounding after it has first absorbed in the compressive phase a large amount of elastic energy. Thus, a design intended to take maximum advantage of the best quality of concrete may be faulty as a result of the response in a tensile reaction which develops stresses that would never occur under conventional loading.

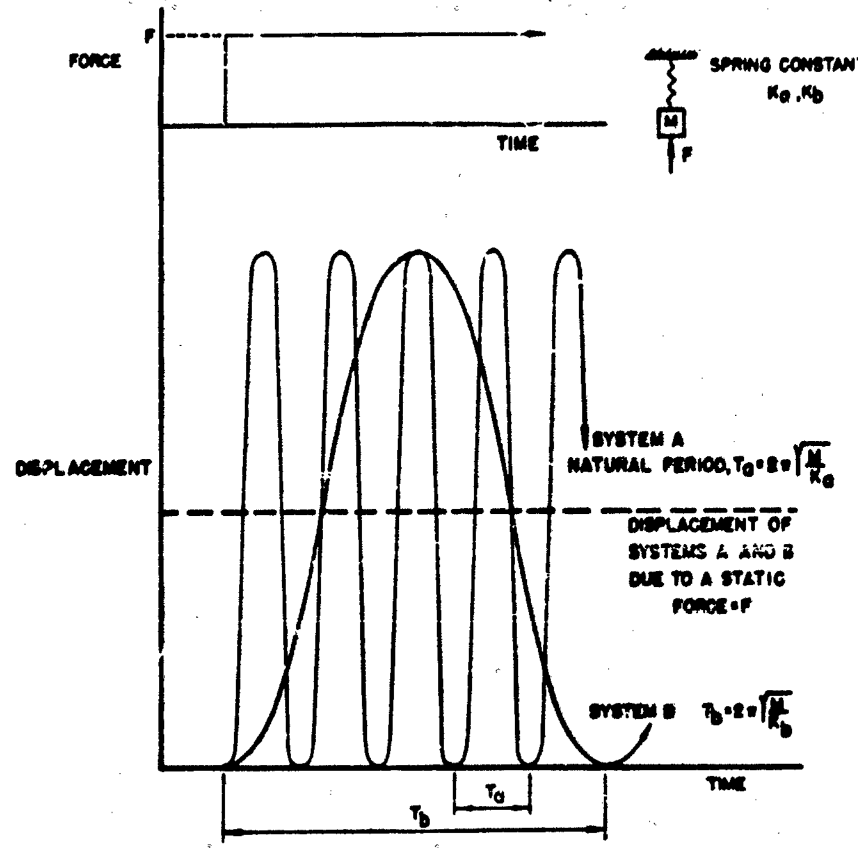


Fig. 6. Fundamental response of undamped long- and short-period systems to a step loading.

An important factor of design for dynamic loads is that certain materials of construction exhibit markedly different properties under high rates of loading. Materials such as timber and steel have strengths in the elastic range under high rates of loading which are higher by a factor of 25 percent to 50 percent than those available when the loads are applied gradually. For example, the yield point of structural steel, approximately 32,000 psi under static load, may be up to 45,000 psi under rapid loading. Even greater dynamic increases in strength characteristics are obtained from timber under rapid loading. These characteristics allow the designer of a structure to use the dynamic strength available in steel or timber to withstand the high pressures which occur in a sharply peaked overpressure pulse.

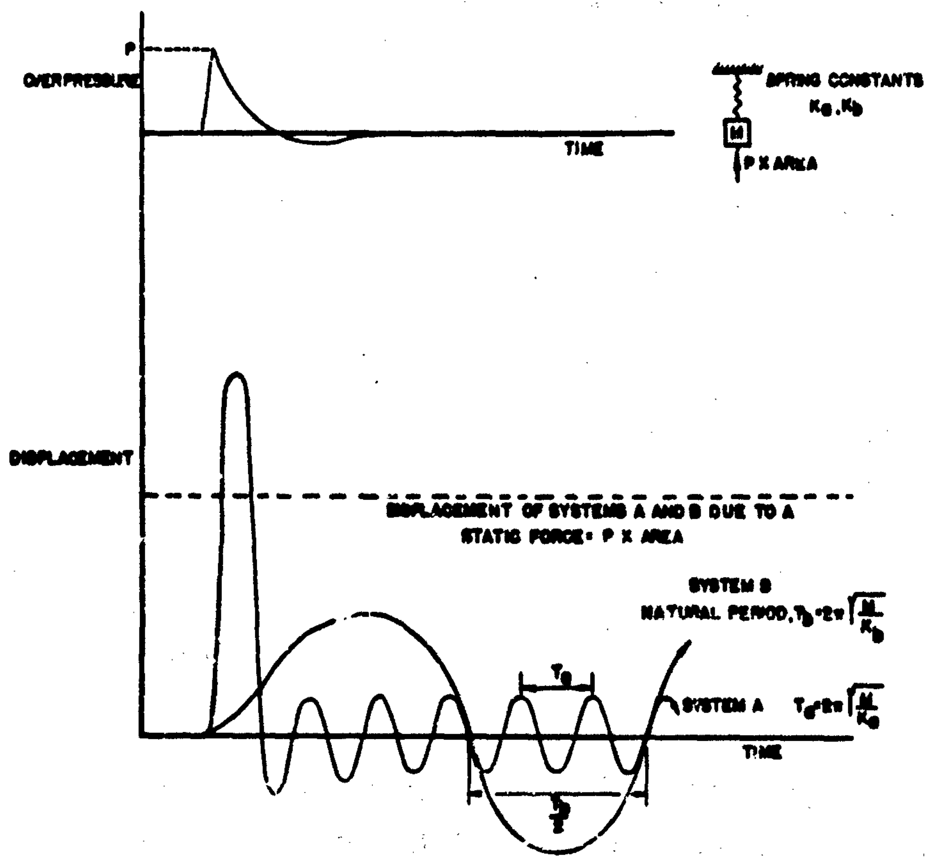


Fig. 7. Fundamental response of undamped long- and short-period systems to a blast pulse.

Another consideration in designing for dynamic loads which sets apart such design from that used for conventional structures is that of the elasto-plastic action of the structural material. Plastic yielding of the structure elements may be permitted to occur under design loads of short duration, an effect which would never be permitted by civil practice. Such design allows for the dynamic response characteristics of the load by making use of the capability of the structural material to absorb some of the effect of loads of short duration. Such action enables high peak overpressures of short duration to be designed for resistance by energy absorption concepts. By these methods, the energy developed in the structural system by the application of the high overpressure is absorbed by plastic deformation of the structural elements; these deformations require energy absorption of such extent and take such a length of time that the system is brought to rest before the ultimate strength is utilized. The employment of this concept also permits the use of lower design moment values for the beam-type structural elements. The development of plastic hinges in continuous beams or rigid frames may be assumed to occur and, consequently, a balanced distribution of movement between ends and center of a beam may also be assumed. These effects and concepts are illustrated in Figs. 8 through 10.

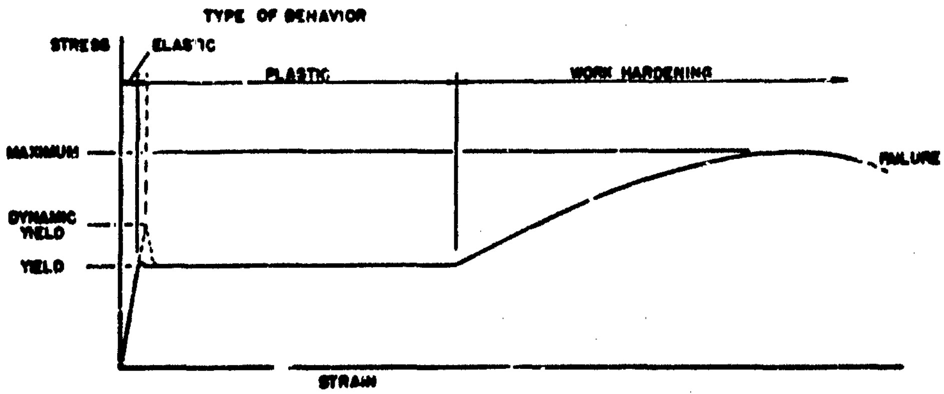


Fig. 8. Idealized stress-strain relationship of intermediate grade steel.

The dynamic response characteristics of a structural element play a large part in the design of that element for response to a specific blast overpressure and decay conditions. The period of vibration of the structural element acting within its elastic range is an important criterion in determining the theoretical response of that element. In addition, the elastic limit of the structural element and the plastic strain which may occur beyond this limit prior to failure are important.

As the side-on overpressure acting on the surface has in itself no momentum, energy is absorbed into the structural system by means of the overpressure acting over a finite distance. The amount of energy absorbed by the system is determined by the distance over which the overpressure acts when it is at varying pressures. For example, the longer the response time of the structural element, the shorter will be the distance over which a given decaying overpressure will act during the time of that decay. Thus, the energy absorbed will be smaller and the capacity to absorb this energy will be less. This action was illustrated previously in Fig. 7.

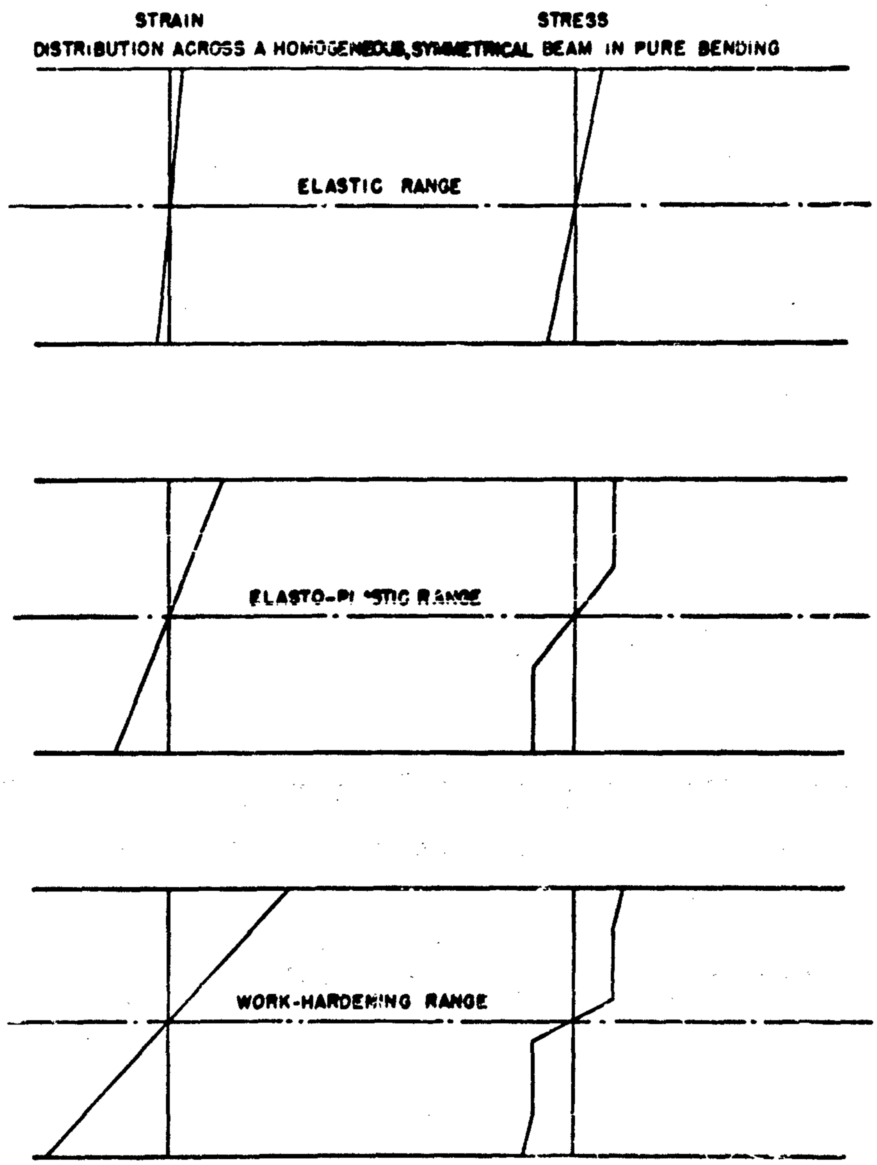


Fig. 9. Distribution of stress and strain across a beam in pure bending.

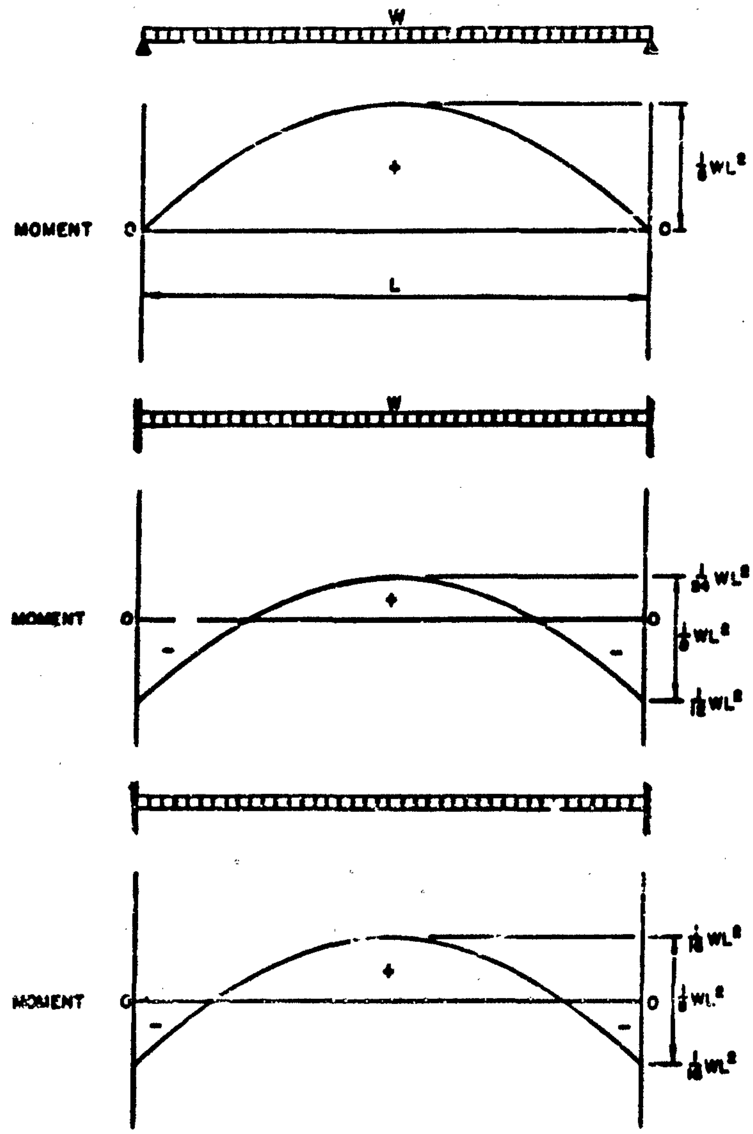


Fig. 10. Effect of plastic hinges upon the moment distribution along a beam. The upper diagram illustrates moment distribution along a simply supported beam. The center figure shows the moment distribution along a fully elastic beam with rigid end supports. In the lower figure, plastic hinges formed at the ends of the beam permit an increase in load up to the formation of a plastic hinge at midspan.

6. Consideration of Ultimate Strength Designs. In conventional construction, general design procedures utilize allowable stresses within the structural elements based on a percentage of the yield stress of the material. Ultimate strength design in conventional construction utilizes the ultimate strength of the material and to this relates a factor of safety for computation of the allowable stresses. The actual factor of safety against failure may be higher or lower for this type of design procedure. Failure may be considered as yield or as collapse of a structure. In conventional construction, design is intended to avoid the possibility of the occurrence of yield. With the high pressures applied and strength requirements for protection against the effects of nuclear blast, the avoidance of yield places too large a requirement upon the strength of structural elements. Consequently, the design based on ultimate strength may provide for a more balanced structure in which the various components are at the same percentage of their ultimate capacity under design loading. However, with the design of structure for protection against the effects of nuclear blast, ultimate strength design takes on a different aspect.

The forces of these blasts are of such a magnitude and create such stresses that the structures cannot economically be designed so that all responses will be within the elastic range under design loadings. The structures are designed to permit some plastic deformation of the structural elements under maximum design loads. The principal application of ultimate strength design both in civil and protective construction is with steel as the responding material. Steel has a strain at failure which may be on the order of 20 or 30 times the strain of initial yield and the ultimate load may be on the order of 2 times that at which yield occurred (Fig. 8). Within the elastic range of behavior the stresses in structural members are essentially proportional to strain. At the ultimate condition stresses and strains are not proportional, do not vary proportionally, and the distribution of compressive stresses in an element subjected to bending is nonlinear. Figure 9 illustrates this variation in stresses across a bending member in these various conditions.

7. Use of Empirical Results. Nuclear weapons effects tests have included tests on berm configurations, structures, and structure and utility components. These tests have proved the ability of specific structures to provide blast protection and have indicated the manner and the pressure levels at which these structures undergo permanent deformation or collapse. Specific structures of steel, concrete, and timber in rectangular, circular, semicircular or other shapes have been tested. Many forms of end walls, entrances, closures, and entrance configurations have been employed. The empirical results of these tests have been used as the principal design criteria for the structural and utility elements selected for the design system. These empirical test results have been reduced to

components whereby a structure which may have failed may have provided positive blast protection as far as the design of the entrance or closure was concerned. Theory which has been developed from the nuclear test results or from dynamic or ultimate strength tests has been used to extrapolate the derived designs for which no test results upon a similar element were available. The principal closure designs are an example of this; both the massive drawbridge door and the designed personnel hatch are adaptions with minor modifications of similar closures which have received nuclear or high explosive blast testing.

Earth berms cause semiburied structures to respond as though they were fully buried. Other berms which have been tested have failed to provide such an effect and the structures have exhibited failure as a result of the reflected overpressure developed on the side face of the berm. The designs for berms which are of a wide variety have received little comprehensive testing. Hence, it is recommended that the use of any berms be discouraged and that fully buried placement be used. Consequently, no designs for berms are presented in this report. Likewise, no designs are presented for an aboveground uncovered structure because the magnitudes of the reflected and drag pressures developed on the sides of such a structure prohibit such placement. It is recognized that the requirements of entrance or subsoil conditions may necessitate semiburied construction. Technical Manual TM5-311 presents berm designs based on positive nuclear test results which will provide the means by which the buried structure designs may be used for semiburied structure placement.

III. STRUCTURES COMPONENTS DESIGN

8. General. This section presents families of structures and structural components which are designed to provide protection against the blast effects of nuclear detonations at design overpressure levels. The bases for selection and the design criteria of the structural components and basic structures are described. A breakdown of protective structure design into structures and components enables each component to act independently and thus be designed using independent criteria. The structures are to be fully buried. The classification of the structures and components follows:

a. Basic structures.

b. End walls.

c. Entrance configurations.

d. Blast resistant closures and frames.

e. Door frame-supporting foundations.

f. Floors.

The analyses and design of structures and components have been made by considering the results of past nuclear and high explosive tests with reference to each of the classifications just mentioned. With this procedure, a test which may have caused basic structure collapse may still have provided positive results allowing determination of a suitable design for entrance configuration or for a blast resistant door frame or frame-supporting foundation. Similarly, positive and negative results were employed to bracket the optimum design or the overpressure at which such a structure is likely to undergo failure. Analyzing test results by components of the structure permits alteration of the tested design in such a fashion that the same structure may withstand greater overpressures than those which caused failure during the test. This method of analysis was applied with the criteria set forth in the preceding section to effect the designs presented here.

9. <u>Basic Structures</u>. Basic structures are presented to provide blast resistance when the structure is in the fully buried condition for any direction of travel of blast waves with respect to its orientation. The length of the basic structure is immaterial because a cross section perpendicular to the longitudinal axis can be taken at any location along the length of the structure and still provide full protection against blast forces. To accomplish this adequately, the structure must have the capacity to withstand the full forces of the blast across its axis. If longitudinal structural members are employed, they must bear on a transverse structural section and should be in independently acting segments or modules. In addition, the end wall must be such that negligible or no forces are transmitted to the structure in the longitudinal direction. Thus, any need for a different design to provide stronger ends for the basic structure than for the center section will be eliminated. The amount of force that can be transmitted to the structure longitudinally by the end wall varies with the structure type. For example, a reinforced concrete arch section can withstand a much higher longitudinal force imposed by the end wall than can a section of corrugated steel of similar dimension. All of the basic structures presented here are independent of any of the choices made from among the other structural components.

a. <u>Circular Corrugated Steel</u>. Corrugated steel arch and circular shapes have undergone numerous successful tests under nuclear blast overpressure, both as underground horizontal passage or shelter structures and as vertical tubes providing entrance from the surface to a structure or to a horizontal entrance section. As the corrugations run in a circumferential direction, a requirement in the employment of corrugated steel is the avoidance of longitudinal thrust or bending stresses. The curved corrugated steel section is the most efficient material of construction for withstanding uniform loads applied radially or tangentially to an arc section.

Curved corrugated steel sections are produced in nestable sections with flanged longitudinal connections in diameters up to 7 feet and with bolted lap joints in diameters up to 30 feet. These characteristics make the material ideal for field assembly and present a minimum logistic requirement. The flexibility of the corrugated steel in both the longitudinal and circumferential directions allows the steel to retain its strength and resistance to overpressure even with variance in geometry or alignment caused by settlement or assembly tolerances. In addition, when the material is overloaded and partial failure results, in the form of buckling and distortion of the section, a usable area for passage or occupancy is left, allowing continued partial use of the structure or entrance.

The design of the buried corrugated steel arch and circular structures is based upon the mode of failure of such arch structures when they are subjected to uniform blast overpressure on the ground surface. The bases of the design are the nuclear tests in which the structures responded and failed in the compressive mode. The compressive mode is that in which the entire structure is placed in compression tangential to the circumference. During nuclear tests, structures failed in this compressive mode of response; the steel plate yielded under bearing of bolts at longitudinal seams. Structures which had been placed and tested so that a large nonuniform load was placed upon them (aboveground structures for which the berm was insufficient to secure underground response characteristics) failed by buckling of the steel section. Failure in the compressive mode for such structures presents a much more readily calculated ultimate strength for the structure. This permits ultimate strength calculation to be made on the basis of the strength of the bolted longitudinal joints for the various thicknesses of material and spacings of the bolts. When a buried structure is subjected to a uniform load as a result of overpressure applied at the surface, the component of stress tangential to the section and that which creates the failure of the longitudinal seams vary directly with the radius of the structure. In contrast, the resistance of a structure to nonuniform loads creating buckling and requiring the section to resist in flexure varies with the square of the span. In other words as the span increases the same section has resistance to flexure which decreases inversely with the square root of the span. Nuclear test results have shown that a structure of 30-foot diameter subjected to fully buried conditions failed in the compressive mode. This result, and the described variations in resistance of the structure to flexure and failure in the compressive mode provide the basis for assuming failure in this mode of properly placed corrugated steel arch structures with radii of 15 feet and less. Those steel structures which were tested and which failed in the compressive mode were exposed to side-on overpressures ranging from 60 to 200 psi.

Static load tests of the bolted joints of corrugated steel plate of different thicknesses (the steel employed has a yield stress of 27,000 psi to 28,000 psi) and spacing of the bolts were used to define the ultimate strengths of the various gage plates. Based solely on these data, a graph was prepared which related a uniform overpressure to the radius of the structure, from which a thickness with a standard bolt spacing required for blast resistance could be selected. Figure 11 was developed on this basis, using the yield strengths of the bolted joints. The results of all known nuclear tests on corrugated steel arch or circular sections were plotted upon this graph as a check of its validity. Thus, the chart was checked by comparing overpressures which this material had withstood or under which the material had failed to the overpressure designated for a specific radius and thickness of corrugated steel. Test results have not been of such quality that precise failure overpressures can be identified; these pressures have been bracketed for certain radii and gages of steel, however, and have indicated that overpressure (approximately twice that indicated on the graph derived as just stated) would be required to cause complete collapse of the structure. The chart was checked against corrugated steel structures of 1½-foot to 15-foot radii and at overpressure levels up to 200 psi. As can be noted on the graph of longitudinal seam strength (Fig. 12), an increase in strength may be obtained by using six or eight bolts per foot of longitudinal seam. The four-bolt-per-foot spacing is American standard, but the six- or eight-bolt-per-foot patterns require special order in most sizes. The availability of test data, the desirability of using the standard pattern, and the limited strength increase with additional bolts were factors which determined that the design graph should be based on the four-bolt-per-foot pattern. As the flanged corrugated steel section provides a higher strength contact between adjacent plates than does the lapped and bolted plate, the graph provides a slightly higher factor of safety for these sections. Test data upon which to refine the graph further for this type of section are not available; however, the graph should be suitable for the design of these sections. Although the graph was developed using the computed ultimate strength of the sections, the nuclear test results justify its use and indicate an approximate safety factor of two for overpressure on the surface. It is believed that the principal factors which allow this increase in strength over the computed ultimate strength for the buried structure are the attenuation of side-on overpressure, with depth, the relatively long response time for a buried structure in which the earth surrounding the structure acts with the responding structural section, and the higher dynamic yield stresses of steel under dynamic loading.

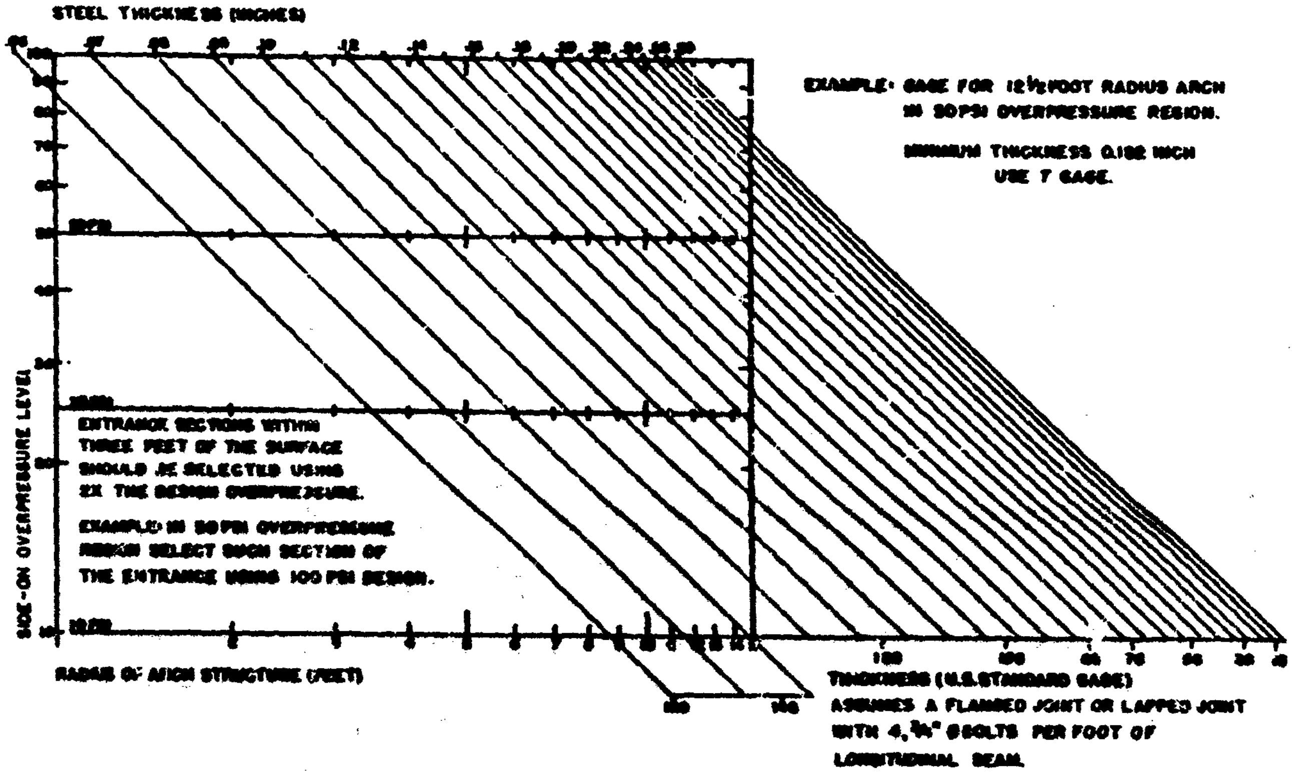


Fig. 11. Corrugated steel gage selection for circular and arch structures.

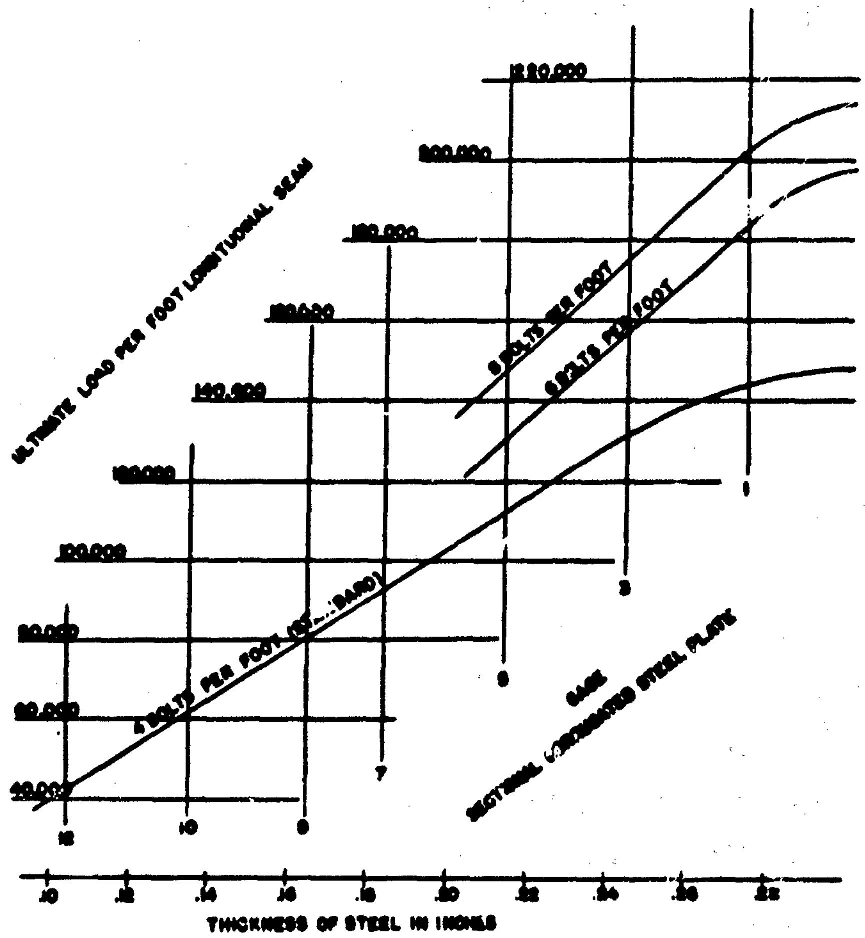


Fig. 12. Corrugated steel longitudinal seam strengths. (Based on a figure by and published with permission of Armco Drainage & Metal Products, Inc.)

In the design graph, entrance sections within 3 feet of the earth's surface should be selected using two times the design overpressure for entry into the graph. This provision is made to allow for the reduction in overpressure within the first few feet from the surface and the absence of a large earth mass responding in conjunction with the structure, as indicated by free-field underground pressure testing and by nondestructive vibration tests. Thereby, as an example, in a design for 50-psi side-on overpressure, a section using 100 psi design overpressure would be selected.

A variation of the sectional circular corrugated steel plate (2-inch depth with 6-inch pitch) for employment as horizontal passage configurations or as small size emergency personnel shelters is the cattle pass section. Figure 13 illustrates the cross section of the cattle pass and Table I presents standard sizes of this section. Such sections have received some tests under nuclear blast overpressures. With the results of this testing as the basis, it is recommended that the circular design chart (Fig. 11) be employed for steel thickness selection for the cattle pass. Half the span of the cattle pass section should be employed as the radius for entry into the graph. Such structures should only be employed in horizontal orientations and with the flat back downward. These structures of 7-foot 8-inch rise 10-gage steel have withstood nuclear blast surface side-on overpressures up to 153 psi without significant damage and, when available, make an excellent section for horizontal passageways.

Circular and arch corrugated steel sections provide the best basic structure. Ease of design, construction, and transportation make steel sections the ideal material for field usage.

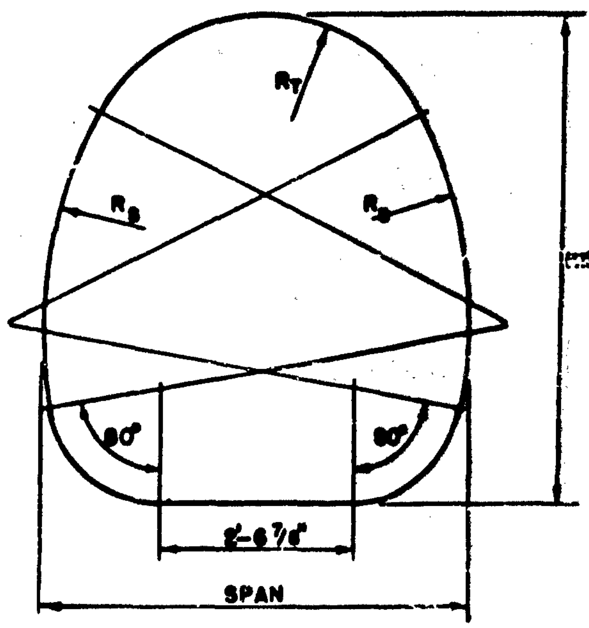


Fig. 13. Corrugated steel cattle pass cross section. Table I contains standard dimensions for this section.

Table I. Typical Dimensions of the Cattle Pass Section[a]

Span (ft-in.)	Rise (ft-in.)	N Required[b] Total	Top	Sides	Inside Radii (in.) R_t	R_s
5 - 8	5 - 9	24	5	5	27-1/2	53
5 - 8	6 - 1	25	6	5	28-1/4	63
5 - 9	6 - 6	26	7	5	29-1/2	75
5 - 9	7 - 0	27	6	6	26-3/4	81-1/2
5 - 9	7 - 4	28	7	6	28-1/2	95-1/4
5 - 10	7 - 10	29	6	7	25-1/2	100-1/2
5 - 10	8 - 2	30	7	7	27-3/4	116-1/2

(a) Refer to Fig. 13 for the cross section with dimension descriptions.

(b) N is the net length of plate longitudinal to the corrugations expressed as the number of standard 9.6-inch spaces between bolt center lines. Thus, the perimeter dimension is total N times 9.6 inches. (The figure 9.6 inches is derived from use of one bolt for each 3 inches of diameter for a circular section.)

b. Corrugated Steel Arch. The design of the steel arch structure employs the steel gage and assembly described in paragraph a, "Circular Corrugated Steel." Variation in design procedure occurs in the requirement for a footing for a bearing of the edge of the structure. Response of the structures is such that no benefits are brought about by use of a tied arch or by obtaining end fixity. Consequently, the footing is designed to fulfill the requirements of the static earth load and to minimize differential settlement under blast loadings. Permanent settlement under such loadings actually lengthens the response time of the structure and thereby increases its dynamic capacity; the steel plate continues to respond as an integral flexible arch and the yielding of the footing absorbs energy. Footing designs for structures of varying spans are presented in Figs. 14 through 16.

The designs of the footings illustrated are based upon the results of tests on footings of reinforced concrete for corrugated arch structures. Such footings have been tested at a wide range of overpressures and structure spans. Significant failure of the footing has not taken place although permanent settlement has occurred. The junction between the footing and a concrete floor poured integral with the footing frequently has failed. The footing designs provide adequate bearing areas for minimum settlement of the

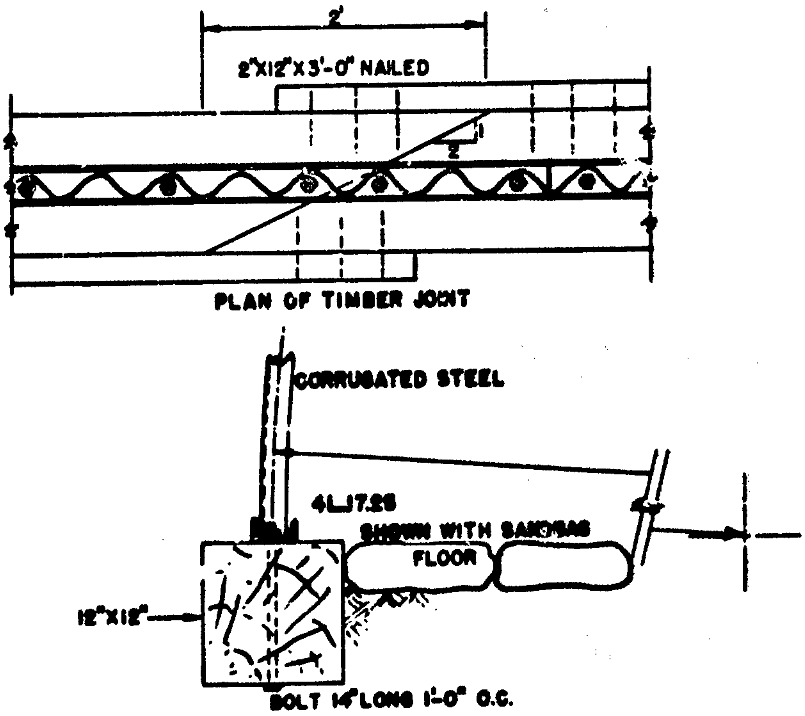


Fig. 14. Timber footing for corrugated steel arch structures.

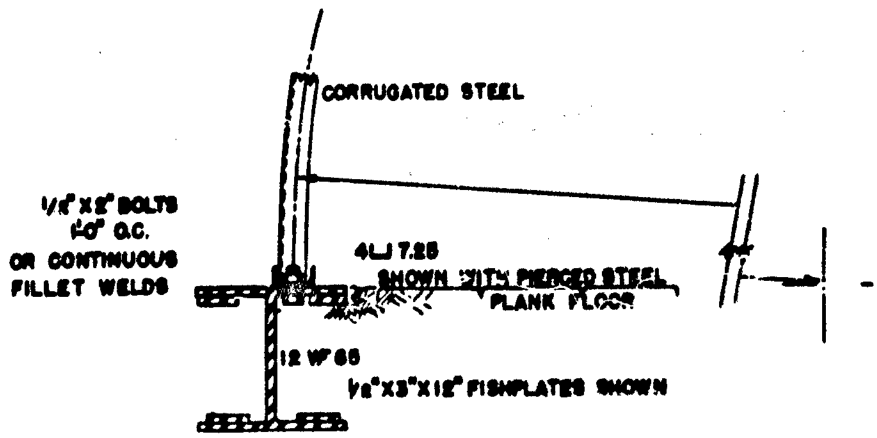


Fig. 15. Rolled steel footing for corrugated steel arch structures.

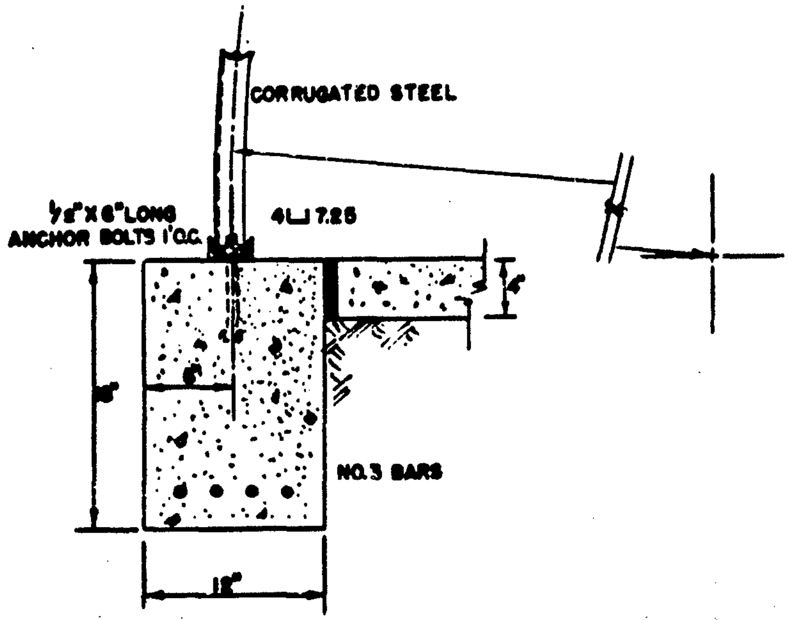


Fig. 16. Concrete footing for corrugated steel arch structures.

structure under static load conditions. All of the designs are intended to provide continuous footing below the edge of the structure. The proved resistance of the reinforced concrete footings was used to establish width of footing and a minimum section modulus for substitution of timber or steel sections as footing. The steel section has greater flexural strength than is required to provide sufficient bearing area.

Of the three designs presented, the timber is most suitable for field usage. Timber is a readily worked material and requires no curing or other time delays inherent in concrete construction. Substitution of steel section for that presented should be made on the basis of maintaining a steel thickness, not subject to adverse weathering effects; and providing adequate bearing and depth (1-foot depth is considered to be a minimum).

c. Circular Reinforced Concrete. Nuclear blast overpressures acting on the ground surface generally create normal forces on the surfaces of buried structures and cause circular or arched structural shapes to be most efficient in withstanding these forces. As previously illustrated, a circular lightweight corrugated steel section may withstand extremely high overpressure because of the type of resultant stresses which are compressive, tangential to the circumference, and, usually, without bending. The relatively high strength of reinforced concrete in pure compression would indicate that it should be an excellent material for circular arch blast resistant construction. One drawback is the difficulty of field forming, bending, and placement of reinforcing steel. Thus, a prefabricated circular section, such as reinforced concrete pipe, may form an effective and readily placed blast resistant module for use in entrance configurations or small structures. Such pipe is usually locally manufactured and is commonly used in sewer or culvert construction. Industry-wide standards of construction, geometry, strength, and reinforcing increase the feasibility of using the pipe sections for blast resistant construction. Nuclear test results on such pipe with blast overpressures up to 136 psi have proved the feasibility of the material and justify its consideration in this report.

A theoretical analysis of the behavior of a circular reinforced concrete section to the shock overpressures is illustrated in Fig. 17 and described as follows:

(1) On the arrival of the shock front, a nonuniform loading is applied to the circular section. This loading consists of the shock pressures acting on the upper portions of the section and the earth reaction acting upward on the lower parts. Structural response to this loading is an initial elliptical deformation; the actual deformation is counteracted by bending resistance of the concrete section and by confining earth pressures. If the section has insufficient bending resistance, cracking is likely to occur at the quarter points, as illustrated.

(2) After the initial peak shock has passed, the structure is enveloped by a uniform radial pressure which decays as the overpressure. The response of the structure is the development of a uniform compressive load, tangential to the circumference, with a resultant tendency of the structure to retain its circular shape.

(3) Negative pressures may occur in the structure during the negative phase of the blast overpressure. Tensile resistance may be required or the reaction to the sudden application and release of the load may cause an elastic rebound in the concrete necessitating tensile strength. Such an action could cause a uniform shattering of the material or more likely, an enlargement of cracks which may have formed during the initial loading phase.

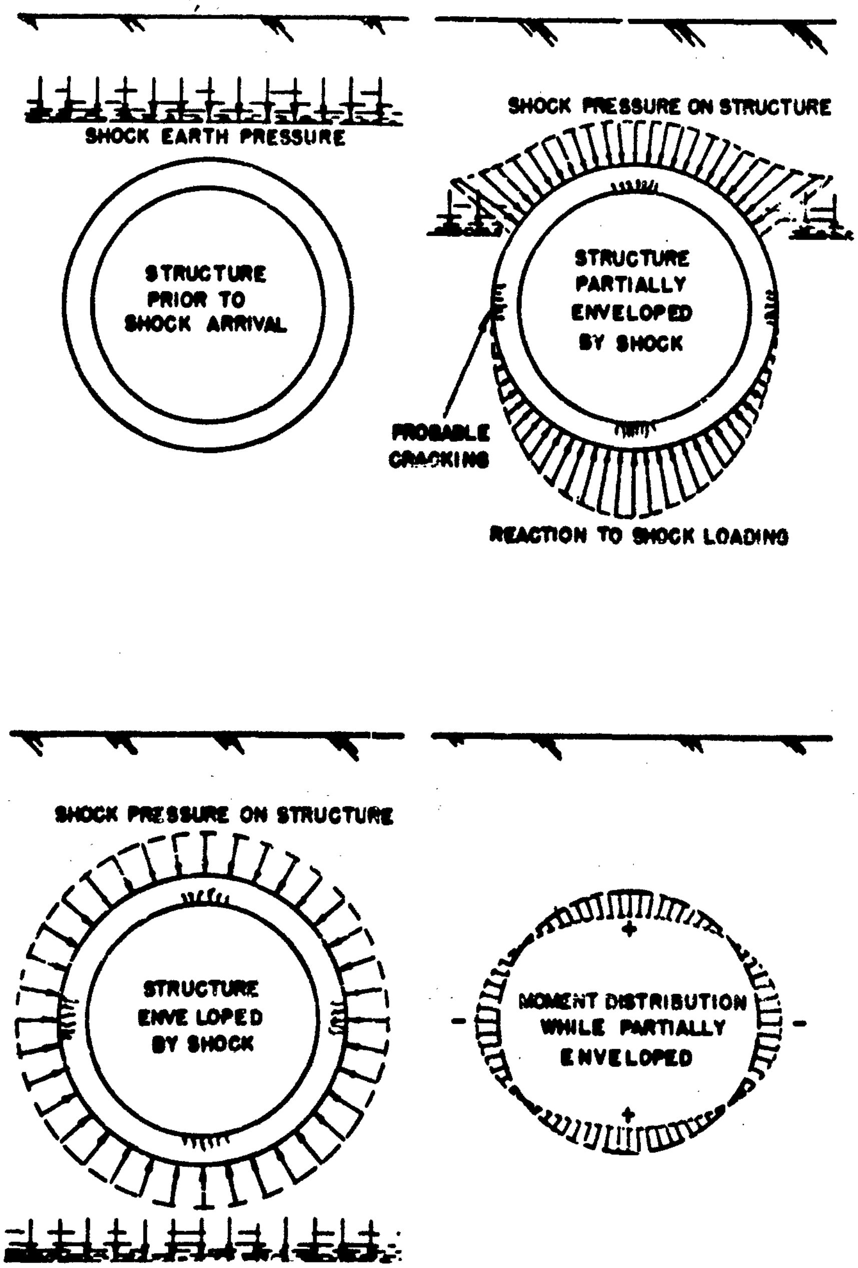


Fig. 17. Idealized interaction of earth shock and a circular concrete structure.

Nuclear and nondestructive tests confirm, by the response of the structure, the deformation, and the cracking, that the structures do respond in both flexural and compressive modes and, consequently, require flexural steel reinforcing. The mechanical properties of the section studied in these tests are set forth as a basic structure for a 50-psi side-on overpressure region. This section withstood 126-psi side-on overpressure, during which $\frac{1}{4}$-inch cracks were formed at the quarter points. At 56-psi side-on overpressure, the cracks were slight and no deformation occurred. A cracked section causes a reduction in the resistance of the structural section to subsequent nuclear blast loadings. Later response would have a tendency to be in the flexural mode. This fact is partially confirmed by nondestructive testing. On this basis and the desirability of a factor of safety, a reduction of strength of the tested section for the 50-psi region of design was not considered justified by the empirical tests of the presented culvert section (Fig. 18).

The section shown in Fig. 18 is of less strength than that specified by American Society of Testing Materials (ASTM Designation: C76-57T) design requirements for Class I reinforced concrete pipe. The other ASTM specifications for reinforced concrete pipe, Classes II through V, provide still greater strengths. Reinforced concrete pipe is graded by strength from a loading test. The results of this test are expressed in pounds per linear foot per foot of diameter as the "D-load to produce a 0.01-inch crack" and the "D-load to produce the ultimate load." The testing procedure for acquiring these "D-loads" is shown in Fig. 19. The identical tested structures which withstood loadings adequately from one nuclear blast up to 126-psi side-on overpressure, had D-load to produce a 0.01-inch crack of 750 (pounds per linear foot per foot diameter) and D-load to produce the ultimate load of 1,100 pounds. The respective D-loads for Class I pipe are 800 and 1,200 pounds; for Class II, 1,000 and 1,500 pounds; for Class III, 1,350 and 2,000 pounds; for Class IV, 2,000 and 3,000 pounds; and for Class V, 3,000 and 3,750 pounds.

When reinforced concrete pipe is available and the method of manufacture is not known, the D-loads should be determined by test on a sample section. As the computation of the D-load provides for the effect of varying strengths for different diameter sections, those pipe sections which meet 750- and 1,100-pound D-loadings for a 0.01-inch crack and ultimate load, respectively, may be considered adequate for 50-psi side-on overpressure. This fact is true in horizontal structure or in vertical entrance employment for all diameters of a section. Provision for stronger sections close to the surface is not considered necessary because of the probable reduced magnitude of flexural action when the shock is traveling parallel to the longitudinal axis of a vertical entrance section.

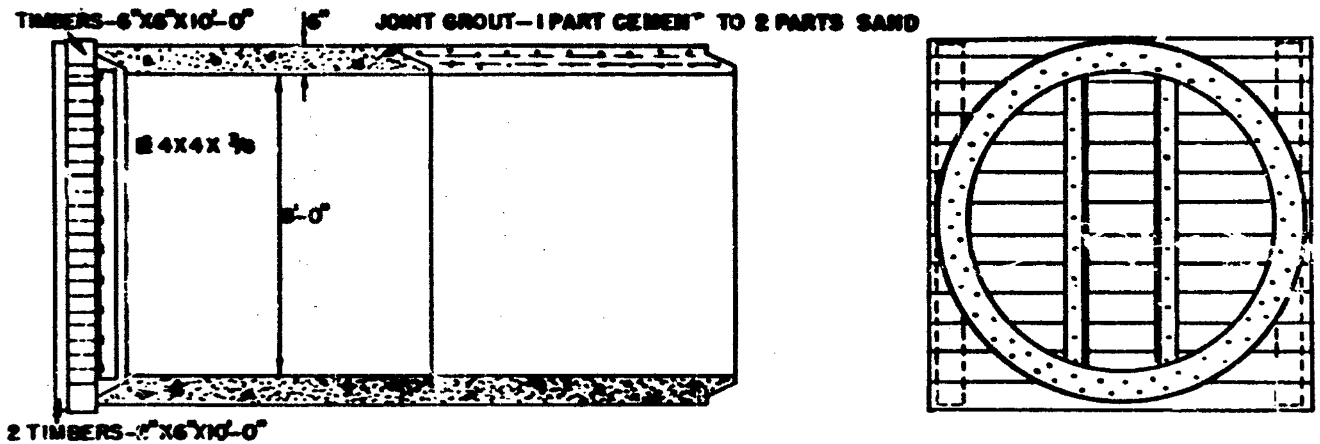


Fig. 18. Tested circular concrete section. The section which met standard Specification ASTM 75-55 weighs $1\frac{1}{2}$ tons per foot of length.

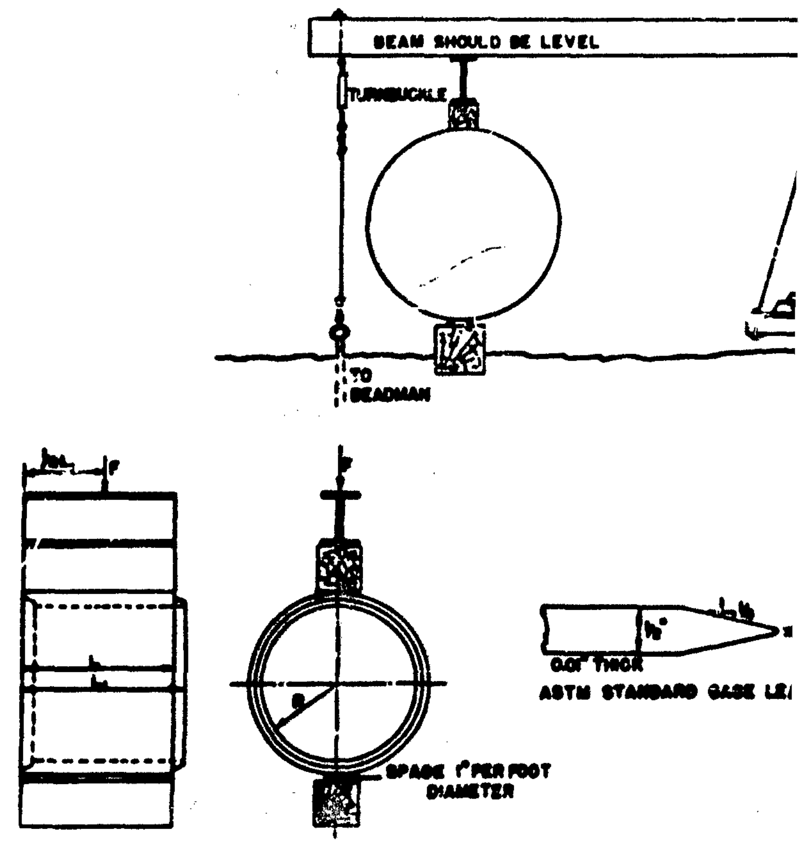


Fig. 19. D-load test for circular concrete sectio

d. Timber. Limited tests have been made in whi timber structures have been subjected to nuclear blast load the point of complete collapse. Failure of structural roof has been in both tensile and compressive modes in bending a zontal shear. The bending failure predominates only on the of the spans tested, that is, 9 feet. The absence of compl data and information by which a fully proved empirical desi may be formulated is insufficient cause to reject the advan timber structures for protective construction.

Timber is construction material which is rea worked and assembled with field tools and without heavy lif equipment. It is generally available, is familiar to field struction, and provides many side advantages for military u

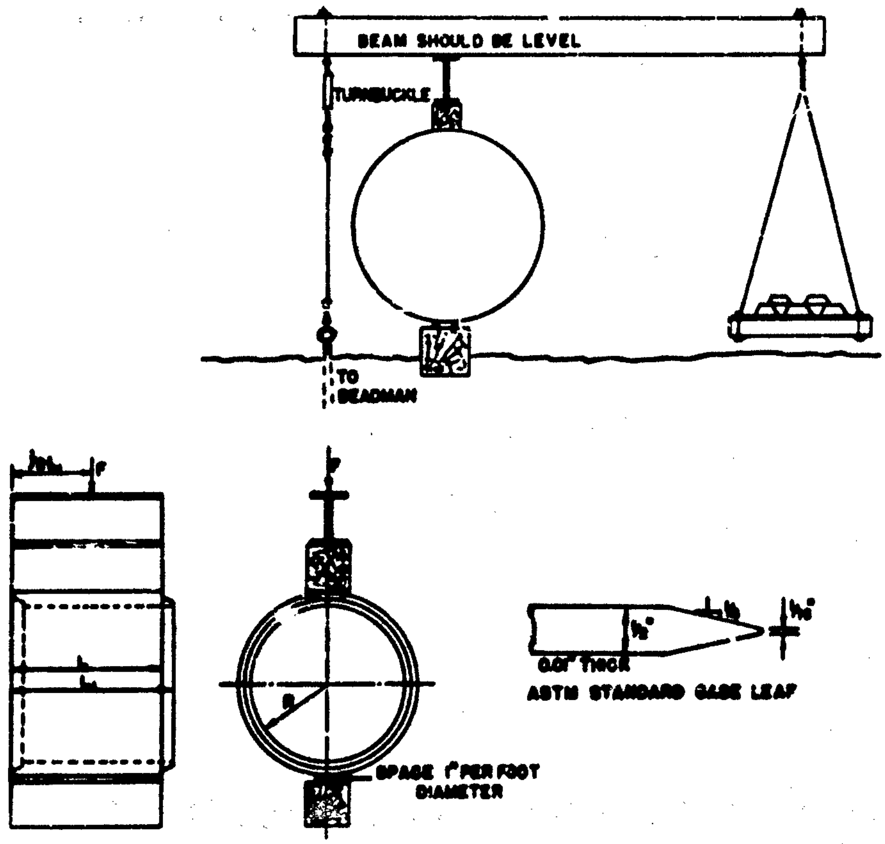


Fig. 19. D-load test for circular concrete sections.

d. Timber. Limited tests have been made in which buried timber structures have been subjected to nuclear blast loading up to the point of complete collapse. Failure of structural roof members has been in both tensile and compressive modes in bending and horizontal shear. The bending failure predominates only on the longest of the spans tested, that is, 9 feet. The absence of complete test data and information by which a fully proved empirical design system may be formulated is insufficient cause to reject the advantages of timber structures for protective construction.

Timber is construction material which is readily worked and assembled with field tools and without heavy lifting equipment. It is generally available, is familiar to field construction, and provides many side advantages for military utilization.

Timber has a high dynamic strength and a flexibility, both in the individual members and in assembly. It has a high-energy absorption past initial yield or cracking, which can allow a structure to remain usable after conditions of failure. This high dynamic strength and long "plastic" yielding range of a structure assembly after partial failure is especially advantageous for the short-term initial high peak loads imposed by blast pressures. Thus, although a design should avoid yield (for example, cracking in horizontal shear) under the design overpressure, the resulting structure would provide protection for much higher overpressures on a one-time basis. After yielding and deformation has occurred, however, the resistance to subsequent blast overpressures would be greatly reduced.

Because of the variety of timber employed for structural purposes, a design based on one set of allowable stresses might be overconservative or unsafe if another type of timber is employed in construction. Strength properties of common structural woods are presented as Table II. Military working stresses for Douglas fir and southern pine are as shown here. (Cf. Field Manual 5-34, Section VII.)

Bending: 2,400 psi
Shear parallel to the grain: 150 psi
Bearing perpendicular to the grain: 500 psi
Modulus of elasticity: 1,600,000 psi

The procedure used for design is to select representative values of allowable stresses, correct these values for impact, and develop an appropriate design procedure which may be altered to suit the strength characteristics of a different variety of timber.

This design of timber installations is based upon fully buried structure placement, 50-psi side-on overpressure at surface, and average values for allowable extreme fiber stress and in horizontal shear. Computations are based on these averages: An allowable fiber stress of 2,000 psi in bending; and a horizontal shear stress of 130 psi. The strength of timber varies to such an extent, depending on type of wood, grade, and condition, that the results obtained in the presented structures should be verified as to applicability for field use. Permissible spans or timber thicknesses may be varied by recomputation of span or depth criteria for lumber of varied strengths. Simply supported, uniformly loaded beam conditions are used. Design is based on a 1-inch-wide section of depth, h; clear span, L; and a uniform dynamic load of w (psi). The allowable stresses are raised by 100 percent to allow for the increased resistance of timber to impact loading, resulting in a design f, extreme fiber stress in bending, of 4,000 psi, and H, horizontal shear stress (shear parallel to the grain), of 260 psi. The validity of this assumption with retention of a factor of safety

Table II. Strength Properties of Some Commercially Important Woods Grown in the United States (results of tests on small,[a] clear specimens in the green and air-dry condition[b])

Commercial Name of Species	Moisture Content (%)	Specific Gravity[c]	Static Bending: Fiber Stress at Proportional Limit (psi)	Static Bending: Modulus of Elasticity (1,000 psi)	Impact Bending[d]: Fiber Stress at Proportional Limit (psi)	Impact Bending[d]: Height of Drop Causing Complete Failure (50-lb hammer) (in.)	Compression Parallel to Grain: Fiber Stress at Proportional Limit (psi)	Compression Parallel to Grain: Maximum Crushing Strength (psi)	Compression Perpendicular to Grain Fiber Stress at Proportional Limit (psi)	Shear Parallel to Grain Maximum Shearing Strength (psi)
Alder, red	98	0.37	3,800	1,170	8,000	22	2,620	2,960	310	770
	12	0.41	6,900	1,380	11,500	20	4,530	5,820	540	1,080
Ash, black	85	0.45	2,600	1,040		33	1,690	2,300	430	860
	12	0.49	7,200	1,600		35	4,520	5,970	940	1,570
Ash, commercial, white	43	0.54	5,300	1,400	12,800	37	3,360	4,060	860	1,350
	12	0.58	8,900	1,680	17,000	40	5,580	7,280	1,510	1,920
Ash, Oregon	48	0.50	4,200	1,130	8,900	34	2,760	3,510	650	1,190
	12	0.55	7,000	1,360	13,300	33	4,100	6,040	1,540	1,790
Aspen	94	0.35	3,200	860	7,000	22	1,670	2,140	220	660
	12	0.38	5,600	1,180	9,000	21	3,040	4,250	460	850
Basswood	105	0.32	2,700	1,040	6,300	16	1,690	2,220	210	600
	12	0.37	5,900	1,460	9,800	16	3,300	4,730	450	990
Beech	54	0.56	4,300	1,380	11,500	43	2,550	3,550	670	1,290
	12	0.64	8,700	1,720	16,000	41	4,880	7,300	1,250	2,010
Birch	62	0.57	4,400	1,560	11,100	48	2,640	3,510	550	1,160
	12	0.63	10,100	2,070	20,000	52	6,200	8,310	1,250	2,020
Birch, paper	65	0.48	3,000	1,170	8,000	49	1,640	2,360	340	840
	12	0.55	6,900	1,590	12,400	34	3,610	5,690	740	1,210
Butternut	104	0.36	2,900	970	7,300	24	2,020	2,420	270	760
	12	0.38	5,700	1,180	11,200	24	4,200	5,110	570	1,170
Cedar, Alaska	38	0.42	3,800	1,140	9,100	27	2,500	3,050	430	840
	12	0.44	7,100	1,420	12,200	29	5,210	6,310	770	1,130
Cedar, eastern red	35	0.44	3,400	650	7,000	35	2,540	3,570	860	1,010
	12	0.47	3,800	880	8,500	22		6,020	1,140	
Cedar, incense	108	0.35	3,300	840	7,300	17	2,940	3,150	460	830
	12		5,300	1,040	9,600	17	4,760	5,200	730	880
Cedar, northern white	55	0.29	2,600	640	5,300	15	1,490	1,990	290	620
	12	0.31	4,900	800	7,100	12	2,630	3,960	380	850
Cedar, Port Orford	43	0.40	4,300	1,420	9,200	22	2,770	[illegible]	350	830
	12	0.42	7,700	1,730	13,500	28	5,890	[illegible]	760	1,080

Cedar, southern white	35	0.31	2,500	750	600	18	1,660	2,390	300	690
	12	0.32	4,800	930	7,600	13	2,740	4,700	500	800
Cedar, western red	37	0.31	3,200	920	6,900	17	2,470	2,750	340	710
	12	0.33	5,300	1,120	8,600	17	4,360	5,020	610	860
Cherry, black	55	.47	4,200	1,310	10,200	33	2,940	3,540	440	1,130
	12	.50	9,000	1,490	13,600	29	5,960	7,110	850	1,700
Chestnut	122	0.40	3,100	930	7,900	24	2,080	2,470	380	800
	12	0.43	6,100	1,230	10,700	19	3,780	5,320	760	1,080
Cottonwood, eastern	111	.37	2,900	1,010	7,200	21	1,740	2,280	240	680
	12	.40	5,700	1,370	7,300	20	3,494	4,910	470	930
Cottonwood, northern black	132	.32	2,900	1,070	6,800	20	1,760	2,160	200	600
	12	.35	5,300	1,260	9,800	22	3,270	4,420	370	1,020
Cypress, southern	91	0.42	4,200	1,180	8,800	25	3,100	3,580	500	810
	12	0.46	7,200	1,440	10,400	24	4,740	6,360	900	1,000
Elm, American	89	0.46	3,900	1,100		38	1,920	2,910	440	1,000
	12	0.50	7,600	1,340		39	4,030	5,520	850	1,510
Elm, rock	48	0.57	4,600	1,190		54	2,970	3,780	750	1,270
	12	0.63	8,000	1,540		56	4,700	7,050	1,520	1,920
Elm, slippery	85	0.48	4,000	1,230	9,200	47	2,790	3,320	510	1,110
	12	0.53	7,700	1,490	15,300	45	4,760	6,360	1,010	1,630
Fir, balsam	117	0.34	3,000	960	6,900	16	2,080	2,400	210	610
	12	0.36	5,200	1,230	7,800	20	3,970	4,530	380	710
Fir, commercial white	108	0.36	3,800	1,120	8,300	22	2,470	2,910	360	750
	12	0.38	6,300	1,470	11,200	20	3,870	5,380	610	930
Fir, Douglas, Coast region	36	0.45	4,800	1,550	9,800	24	3,410	3,890	510	930
	12	0.48	8,100	1,920	12,700	30	6,450	7,420	910	1,140
Fir, Douglas, Inland Empire region	42	0.41	3,600	1,340	8,700	22	2,460	3,240	500	870
	12	0.44	7,400	1,610	11,800	27	5,520	6,700	950	1,190
Fir, Douglas, Rocky Mountain region	38	0.40	3,600	1,180	9,100	20	2,540	3,000	450	880
	12	0.43	6,300	1,400	12,100	26	4,660	6,060	820	1,070
Gum, black	55	0.46	4,000	1,030	8,800	30	2,490	3,040	600	1,100
	12	0.50	7,300	1,200	14,500	22	3,470	5,520	1,150	1,340
Gum, red	81	0.44	3,700	1,150	10,000	33	2,230	2,840	460	1,070
	12	0.49	8,100	1,490	16,800	32	4,700	5,800	860	1,610
Gum, tupelo	97	0.46	4,200	1,050	9,000	30	2,690	3,370	590	1,190
	12	0.50	7,200	1,260	12,500	23	4,280	5,920	1,070	1,590
Hackberry	65	0.49	2,900	950	7,900	49	2,070	2,650	490	1,070
	12	0.53	5,900	1,190	13,700	43	3,710	5,440	1,100	1,590
Hemlock, eastern	111	0.38	3,300	1,070	7,900	21	2,600	3,080	440	850
	12	0.40	6,100	1,200	10,700	21	4,020	5,410	800	1,060
Hemlock, western	74	0.38	3,400	1,220	8,100	22	2,480	2,990	390	810
	12	0.42	6,800	1,490	12,400	26	5,340	6,210	680	1,170

Hickory, pecan	(68	0.59	5,300	1,380	14,200	60	3,820	4,320	980	1,260
	12	0.65	9,100	1,780	20,900	57	6,760	8,280	2,040	1,770
Hickory, true	(57	0.65	6,100	1,570	15,700	88	3,650	4,570	1,080	1,360
	12	0.73	10,900	2,180	22,900	75		8,970	2,310	2,140
Larch, western	(58	0.48	4,600	1,350	9,400	24	3,250	3,800	560	920
	12	0.52	7,900	1,710	15,100	32	5,950	7,490	1,080	1,360
Locust, black	(40	0.66	8,800	1,850	18,300	44	6,120	6,800	1,430	1,760
	12	0.69	12,800	2,050	21,100	57	6,800	10,180	2,260	2,480
Locust, honey	(63	0.60	5,600	1,290	11,800	47	3,320	4,420	1,420	1,660
	12		8,800	1,630	15,400	47	5,250	7,500	2,280	2,250
Magnolia, cucumber	(80	0.44	4,200	1,560	9,300	30	2,810	3,140	410	990
	12	0.48	8,000	1,820	14,700	35	4,840	6,310	710	1,340
Magnolia, evergreen	(105	0.46	3,600	1,110	8,600	54	2,160	2,700	570	1,040
	12	0.50	6,800	1,400	13,600	29	3,420	5,460	1,060	1,530
Maple, bigleaf	(72	0.44	4,400	1,100	8,500	23	2,510	3,240	550	1,110
	12	0.48	6,600	1,450		28	4,790	5,950	930	1,730
Maple, black	(65	0.52	4,100	1,330	10,200	48	2,800	3,270	740	1,130
	12	0.57	8,300	1,620	13,500	40	4,600	6,680	1,250	1,820
Maple, red	(62	0.49	3,800	1,390		32	2,360	3,280	500	1,150
	12	0.54	8,700	1,640		32	4,650	6,540	1,240	1,850
Maple, silver	(66	0.44	3,100	940	6,800	29	1,930	2,490	460	1,050
	12	0.47	6,200	1,140	12,400	25	4,360	5,220	910	1,480
Maple, sugar	(58	0.56	5,100	1,550	12,200	40	2,850	4,020	800	1,460
	12	0.63	9,500	1,830	20,600	39	5,390	7,830	1,810	2,330
Oak, red	(80	0.57	4,400	1,360	10,800	43	2,590	3,520	800	1,220
	12	0.63	8,400	1,810	17,000	43	4,610	6,920	1,260	1,830
Oak, white	(70	0.59	4,700	1,200	10,900	42	2,940	3,520	850	1,270
	12	0.67	7,900	1,620	17,400	39	4,350	7,040	1,410	1,890
Pine, lodgepole	(65	0.38	3,000	1,080	7,200	20	2,110	2,610	310	680
	12	0.41	6,700	1,340	9,600	20	4,310	5,370	750	880
Pine, northern white	(68	0.34	3,100	1,020	6,700	17	2,060	2,490	290	660
	12	0.36	6,000	1,280	9,500	19	3,680	4,840	550	860
Pine, Norway	(54	0.44	3,700	1,380	7,500	28	2,410	3,080	360	780
	12	0.18	9,400	1,800	15,900	25	5,330	7,340	830	1,230
Pine, ponderosa	(91	0.38	3,100	970	6,800	20	2,070	2,400	360	680
	12	0.40	6,300	1,260	9,800	17	4,060	5,270	740	1,160
Pines, southern yellow:										
Loblolly	(81	0.47	4,100	1,410	8,900	30	2,550	3,490	480	850
	12	0.51	7,800	1,800	12,100	30	4,230	7,080	980	1,370
Longleaf	(68	0.54	5,200	1,600	10,100	35	3,430	4,300	590	1,040
	12	0.59	9,300	1,990	15,400	34	6,150	6,640	1,190	1,500
Shortleaf	(81	0.46	3,900	1,390	8,600	30	2,500	3,430	440	850
	12	0.51	7,700	1,760	13,600	33	5,090	7,070	1,000	[illegible]

Pine, sugar	(137	0.35	3,400	940	7,400	17	2,330	2,530	350	680
	12	0.36	5,700	1,200	10,700	18	4,140	4,770	590	1,050
Pine, western white	(54	0.36	3,400	1,170	7,600	19	2,430	2,650	290	540
	12	0.38	6,200	1,510	11,900	23	4,480	5,620	540	
Poplar, yellow	(64	0.38	3,400	1,090	8,600	18	1,930	2,420	330	740
	12	0.40	6,100	1,500	13,500	20	3,550	5,290	580	1,100
Redwood (virgin)	(112	0.38	4,800	1,180	8,900	21	3,700	4,200	520	800
	12	0.40	6,900	1,340	10,200	19	4,560	6,150	860	940
Spruce, eastern	(46	0.38	3,300	1,110	7,000	21	2,120	2,600	290	710
	12	0.40	6,500	1,440	11,400	22	4,160	5,590	590	1,070
Spruce, Engelmann	(100	0.31	2,500	830	5,800	14	1,680	1,980	290	590
	12	0.33	6,000	1,160	9,000	15	3,580	4,580	640	1,010
Spruce, Sitka	(42	0.37	3,300	1,230	8,400	24	2,240	2,670	340	760
	12	0.40	6,700	1,570	11,400	25	4,780	5,610	710	1,150
Sugarberry	(62	0.47	3,200	810	9,200	33	1,990	2,800	580	1,050
	12	0.51	6,200	1,140	11,600	36	3,970	5,620	1,240	1,280
Sycamore	(83	0.46	3,300	1,060	8,800	26	2,400	2,920	450	1,000
	12	0.49	6,400	1,420	10,500	26	3,710	5,380	860	1,470
Tamarack	(52	0.49	4,200	1,240	7,800	28	2,930	3,480	480	860
	12	0.53	8,000	1,640	12,500	23	4,780	7,160	990	1,280
Walnut, black	(81	0.51	5,400	1,420	11,900	37	3,520	4,300	600	1,220
	12	0.55	10,500	1,680	16,400	34	5,780	7,580	1,250	1,370

(a) Test specimens were 2 inches by 2 inches in section. Bending specimens were 30 inches long; others were shorter, depending on the kind of test.

(b) The values in the first line are data obtained from tests of green material; those in the second line are data from tests of seasoned material adjusted to an average air-dry condition of 12 percent moisture.

(c) These data were based on weight when specimens were oven dry and on volume when they were green or at 12 percent moisture.

(d) The impact bending test consists of repeated tests of a bending specimen with the hammer at successively higher heights of drop. The deflection of the specimen upon impact is plotted against the height of drop and is used to compute the fiber stress in bending. The "fiber stress at the proportional limit" is determined by reference to the plotted deflection-height of drop curve and the departure of this curve from elastic (straight-line) behavior. The listed values should be used as rough estimates of the relative strength and toughness of the various woods. Although listed to 100 psi, the values may vary by 10 percent with other samples of the identical wood. The ultimate fiber stress in bending is considerably higher than the stress at the proportional limit, but no reliable impact test data on this value are available. For the purpose of consideration for nuclear blast resistance, the value for the height of drop causing complete failure is similarly misleading. The value given is for a specimen which has previously undergone impact tests of progressively higher energy, with the result that the ultimate test is run on a damaged sample. The impact data presented in this table were the best available at the time of this publication.

may be checked by reference to the impact stresses in Table II. The following expressions are used to determine span and depth relations:

$$H = \frac{3V}{2bh}$$

in which

V = total vertical shear at distance h from support

b = breadth of beam equal to 1 inch

and,

$$f = \frac{6M}{bh^2}$$

in which

M = maximum bending moment, taken equal to $1/8\ wL^2$

Roof sections are designed for full side-on overpressure (50 psi); and vertical walls are designed for one-half side-on overpressure (25 psi). This value presupposes less than ideal backfill conditions. Nuclear tests have indicated vertical wall pressures may range from 25 percent roof pressure under excellent (highly compacted) backfill conditions to 100 percent roof pressure with a water-saturated backfill. The overpressure values have been employed as w in the following relations:

Horizontal shear:

$$H = 260 = \frac{3V}{2bh} = \frac{3w(0.5L-h)}{2h}$$

$w = 50$ psi $\qquad h = \frac{L}{8.9}$ minimum

$w = 25$ psi $\qquad h = \frac{L}{15.8}$ minimum

Flexure:

$$f = 4000 = \frac{6M}{bh^2} = \frac{0.75\ wL^2}{h^2}$$

$$w = 50 \text{ psi} \qquad h = \frac{L}{10.3} \text{ minimum}$$

$$W = 25 \text{ psi} \qquad h = \frac{L}{14.6} \text{ minimum}$$

The results just given provide design criteria that the span must not exceed 8-3/4 inches per inch of depth for 50-psi loads or 12-1/2 inches per inch of depth for vertical wall sections. Variations in these design criteria may be made by substituting for H and f other working stresses for the actual timber employed.

The design criteria developed here were used for structures (Figs. 20 and 21); for selection of timber for the end wall (Fig. 18); and for entrance shafts (Figs. 22 and 23).

Use of lumber in semipermanent underground construction requires moisture, insect, and decay protection. Lumber which has been treated with a petroleum-based preservative by a pressure process may be employed in direct contact with the backfill. The

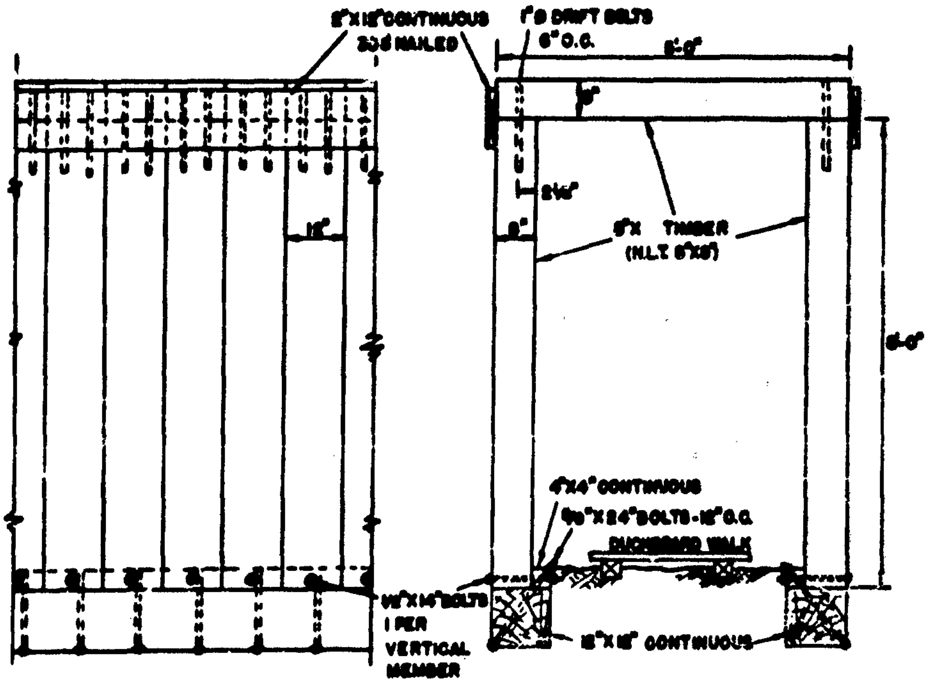


Fig. 20. Basic timber structure: width of passage.

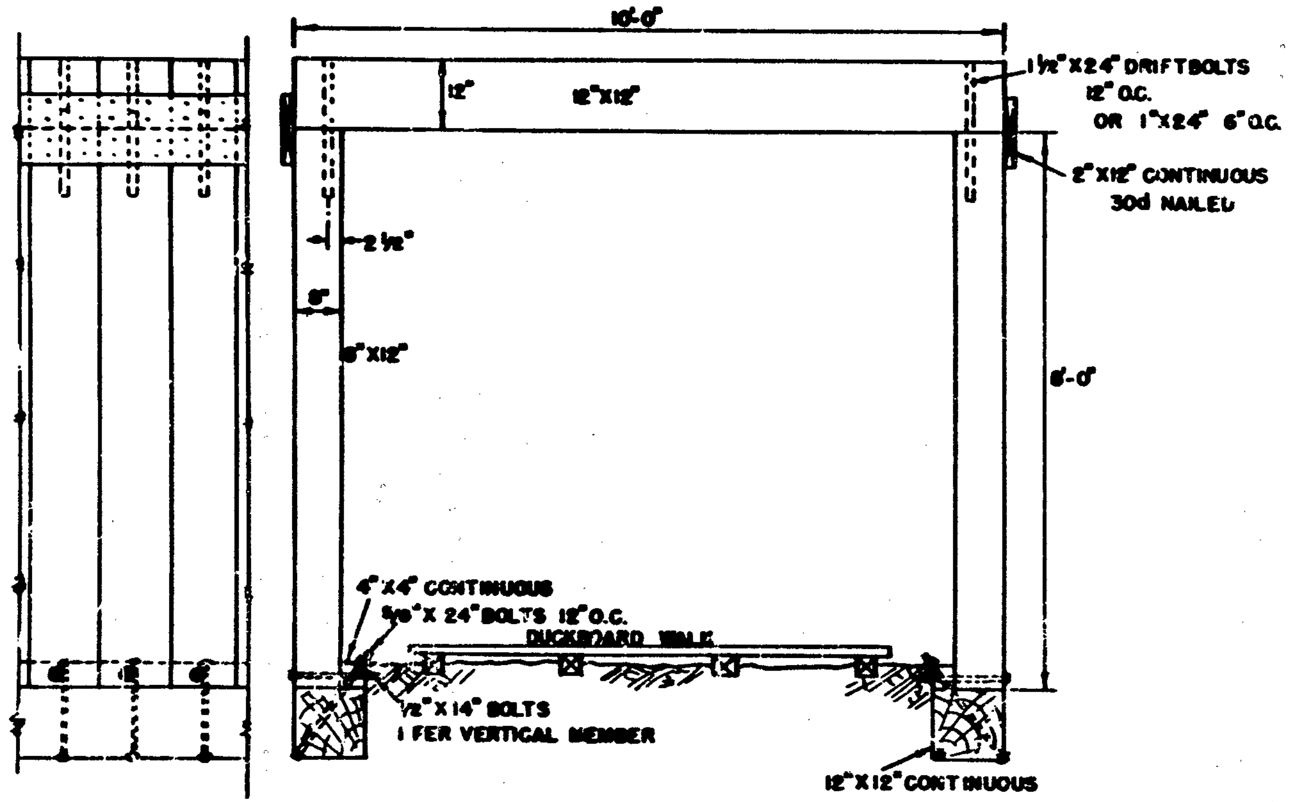


Fig. 21. Basic timber structure; width of shelter.

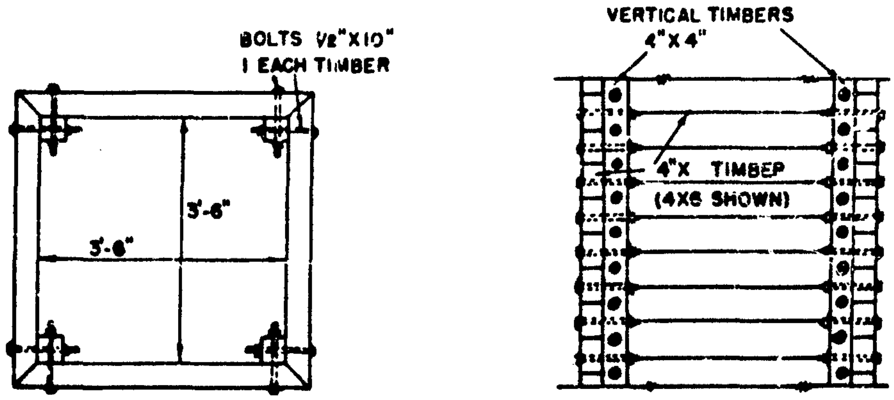


Fig. 22. Timber shaft, 3½ feet by 3½ feet.

odor of some of these preservatives may be objectionable, particularly in a sleeping or long-duration shelter or in a structure without forced ventilation, when they are used for the basic structure, end wall, or sheathing. A cut cross section of the lumber should be examined for preservative penetration, with the possible requirement that all cut surfaces be given additional protection. The non-petroleum-based preservatives in common use are water soluble; consequently, these must be provided additional moisture protection (for example, by special painting in the field) to insure retention of the insect protection. The most extensively used water soluble wood preservative, zinc chloride, is relatively inexpensive, is odorless, holds paint, and presents no fire hazard. Sodium fluoride, to zinc chloride, is similarly acceptable, but is not in extensive use. Principal water soluble preservatives such as arsenic, mercuric chloride, and copper sulphate, in use in Europe and, to some extent, in the United States, are not suitable for underground construction. Arsenic and mercuric chloride are poisonous, and mercuric chloride and copper sulphate corrode iron and steel.

Deadmen should be petroleum-base treated or heavily coated with an asphalt or tar. Exterior sheathing timber should be insect and decay resistant and be protected by a waterproof covering of roofing or paint. Interior structural members should be made insect resistant by preservatives or by thorough painting and shielding. Footings should be given protection equivalent to that provided for deadmen. Generally, the ground over the structure should have good drainage away from the area.

Lumber may be employed as an alternative construction material to straight corrugated steel plate for sheathing end walls

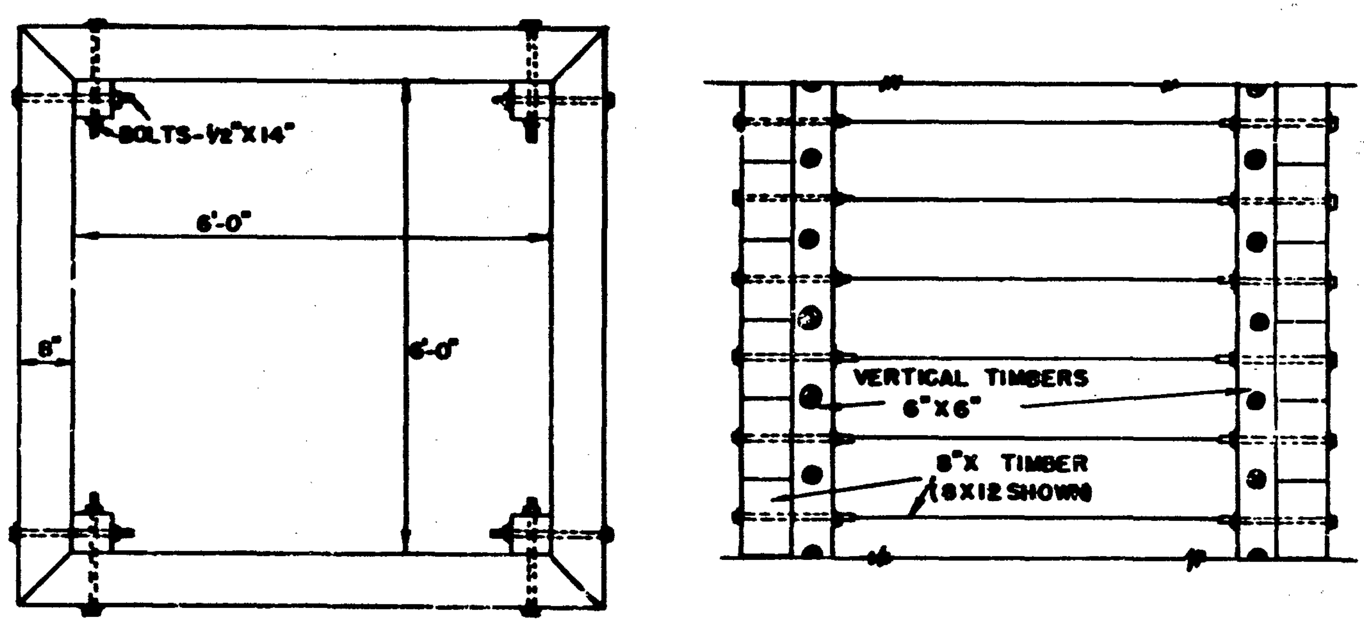


Fig. 23. Timber shaft, 6 feet by 6 feet.

and some basic structures. Table III specifies thickness selection for the lumber alternate and is based upon an allowable fiber stress of 2,000 psi in bending.

Table III. Comparison of Corrugated Steel and Lumber As Sheathing Materials

Corrugated Steel Sheet[a]					Lumber
Gage U.S. Std.	Thickness (in.)	Area[b] ($in.^2$)	Section[b] Modulus ($in.^3$)	Maximum Moment[b][c] (in.-lb / in. width)	Thickness of Lumber to Provide Equivalent Strength[d] (in.)
12	0.1046	0.1297	0.0574	1550	2 - 3/16
10	0.1345	0.1669	0.0732	1970	2 - 1/2
8	0.1644	0.2041	0.0888	2400	2 - 3/4
7	0.1838	0.2283	0.0989	2660	2 - 7/8
5	0.2145	0.2666	0.1147	3100	3 - 1/16
3	0.2451	0.3048	0.1303	3520	3 - 1/4
1	0.2758	0.3432	0.1458	3930	3 - 1/2

(a) Standard heavy corrugation pattern: 2-inch depth with 6-inch pitch.

(b) Per inch of horizontal projection.

(c) Maximum fiber stress used: Steel 27,000 psi
Lumber 2,000 psi

(d) Based on same average stresses as those used in design for timber basic structures.

10. <u>End Walls</u>. End walls are designed so that they do not restrict or determine the level of blast effects a structure can withstand without failure. To fulfill these conditions an end wall must be capable of withstanding surface side-on overpressures higher than those at which the basic structure will fail. Furthermore, it must not place loads upon the basic structure which will increase the overall vulnerability. Desirable characteristics of an end wall are ease of construction; construction by readily available or easily transported materials; ability to provide access to the basic structure for entrances, alcoves, and utilities; and ability to yield to unusual loading conditions without complete failure (high-energy absorption after initial yield). End wall designs which employ the results of nuclear or high explosive tests are developed or presented here.

a. Deadman-Supported End Wall. An apparent solution to avoid weakening of the basic structure by an imposition of forces by the end wall is to design the end wall to act independently of the structure. The prime purpose of an end wall is to provide an integral restraint to earth infiltration into the structure. Thus, such an end wall must provide a seal against the earth action, yet be independently supported. An end wall of this type would be used with a flexible basic structure such as the corrugated steel and timber sections which have restricted capacity to withstand longitudinal loads.

The designs of the enclosed end walls (Figs. 24 through 26) employ sheathing to hold the earth-transmitted pressures, a frame for transferring the load from the sheathing to the connections from the deadmen; and deadmen and footing for horizontal restraint. As shown in the figures, various materials may be used for the sheathing, the frame, and the deadmen. End walls of construction and materials similar to the designs have withstood nuclear blast surface side-on overpressures up to 100 psi. The empirical results of nuclear tests have shown that the capacities of deadmen under such dynamic loading far exceed those computed from static procedures and, consequently, the deadman design is based solely upon these tests. Specifically, the deadmen have been designed to provide a bearing area and resistance to tie rod withdrawal that make the strength of the tie rod the critical element of the restraint system.

With the exception of the deadmen and the employment of dynamic yield stresses, the end wall design is based upon a large equivalent horizontal pressure. The pressure depends on factors of earth berm configuration for semiburied structures, side-on overpressure at the ground surface, and type and compaction of the soil backfill. Theoretical approaches state that the pressure upon a vertical fully buried wall should be taken as one-fourth the side-on overpressure for backfills of cohesionless soils, either damp or dry; one-half the side-on overpressure at surface for backfills of cohesive soils, not saturated; and as high as full side-on overpressure for fully saturated soils with the water table close to the surface. The importance of backfill selection and placement and of structure placement in a well-drained area is emphasized by these coefficients. To allow for variation in the backfill and to provide a structure the strength of which is not limited by a critically designed end wall a factor of one-half the side-on overpressure at the surface has been employed for those end walls not based on test results.

b. Structure and Deadman-Supported End Wall. Concrete structures and flexible structures of relatively small cross sectional area may employ end walls which bear longitudinally upon the basic structure without materially reducing the strength. Such

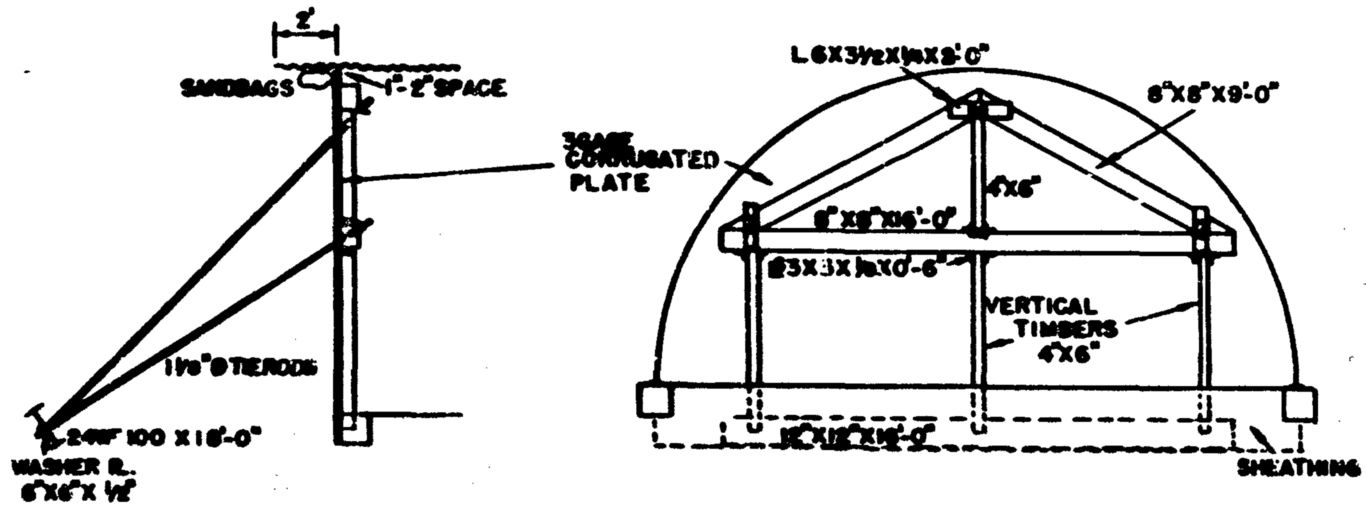


Fig. 24. Deadman-supported end wall for structures up to 10-foot radius.

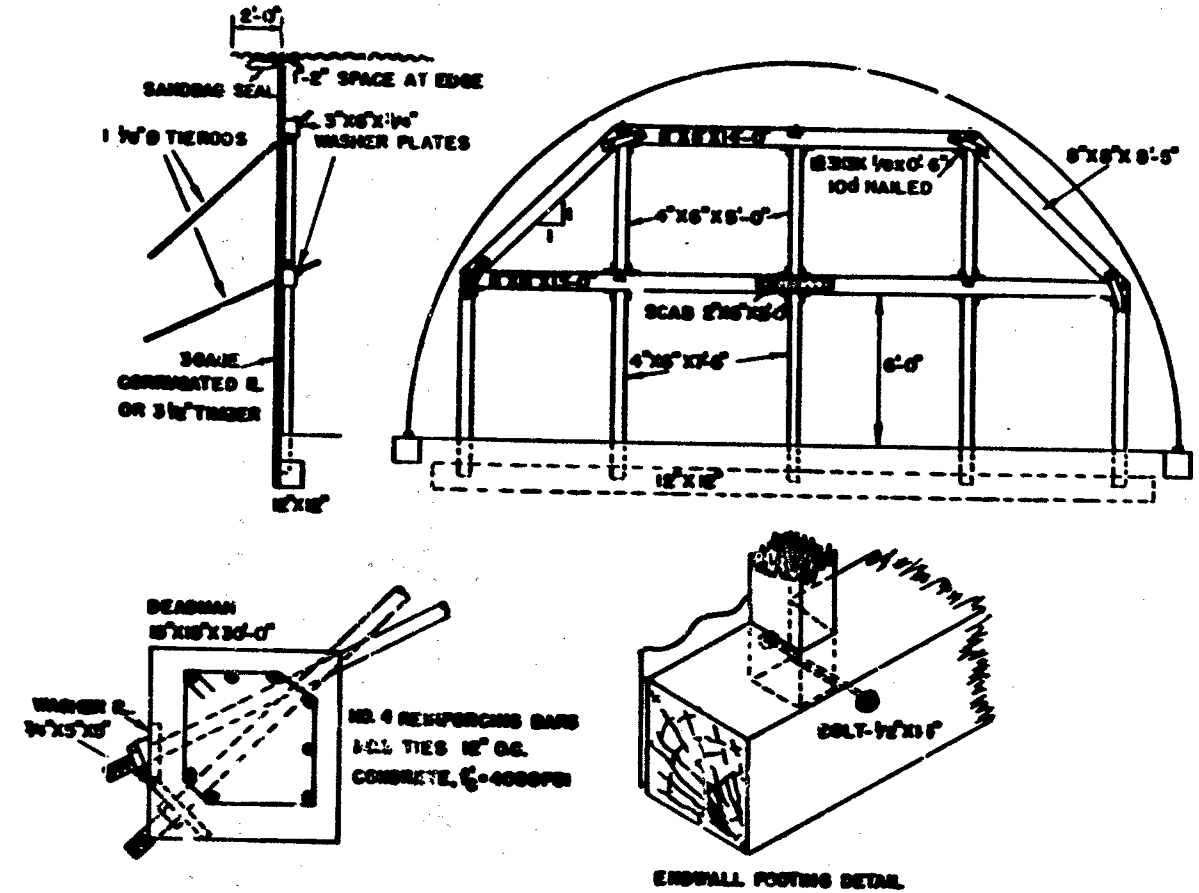


Fig. 25a. Deadman-supported end wall for structures up to 15-foot radius; frame and details.

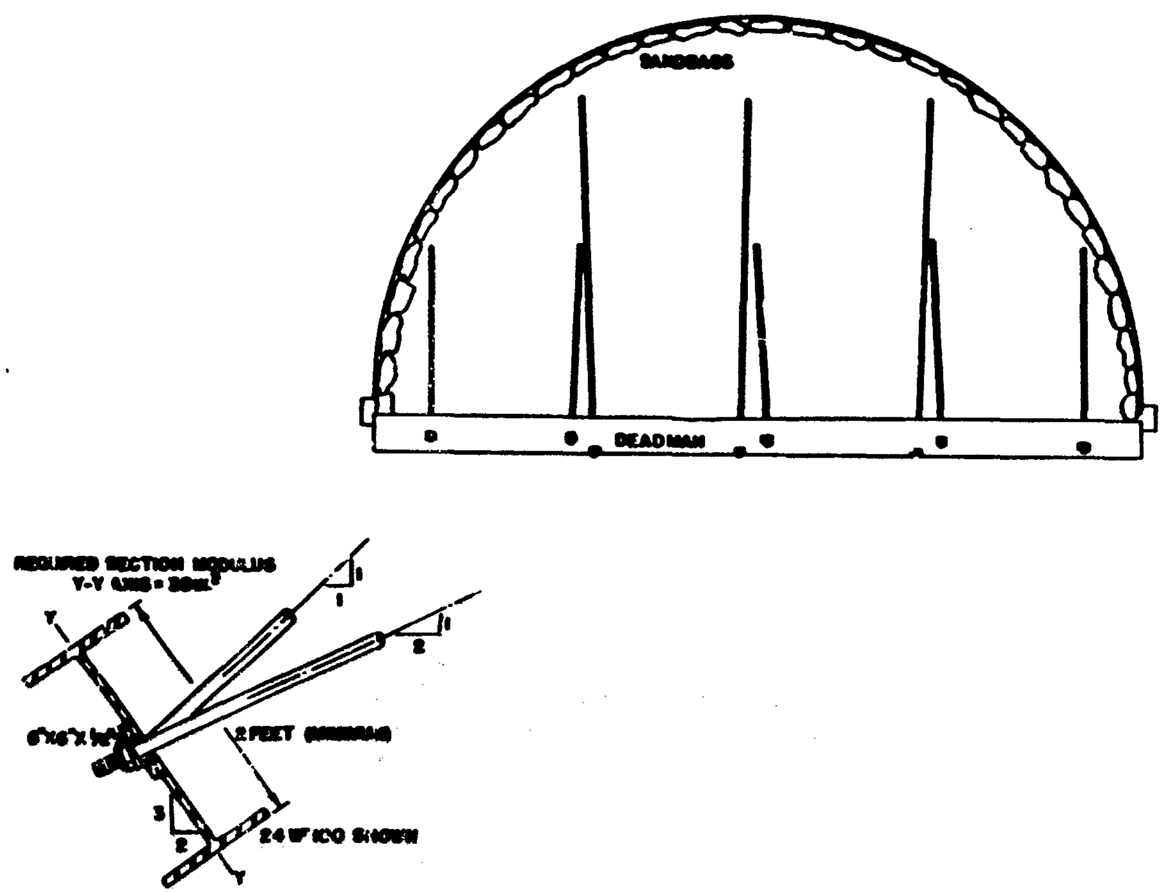


Fig. 25b. Deadman-supported end wall for structures up to 15-foot radius; deadman support.

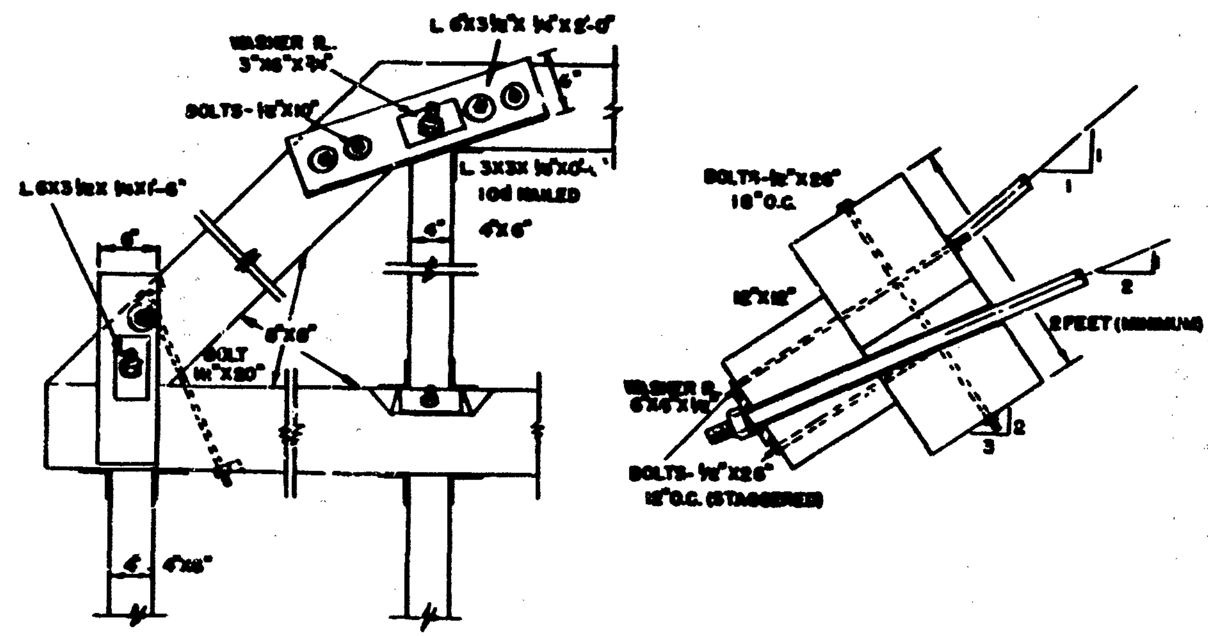


Fig. 25c. Deadman-supported end wall for structures up to 15-foot radius; frame and deadman details.

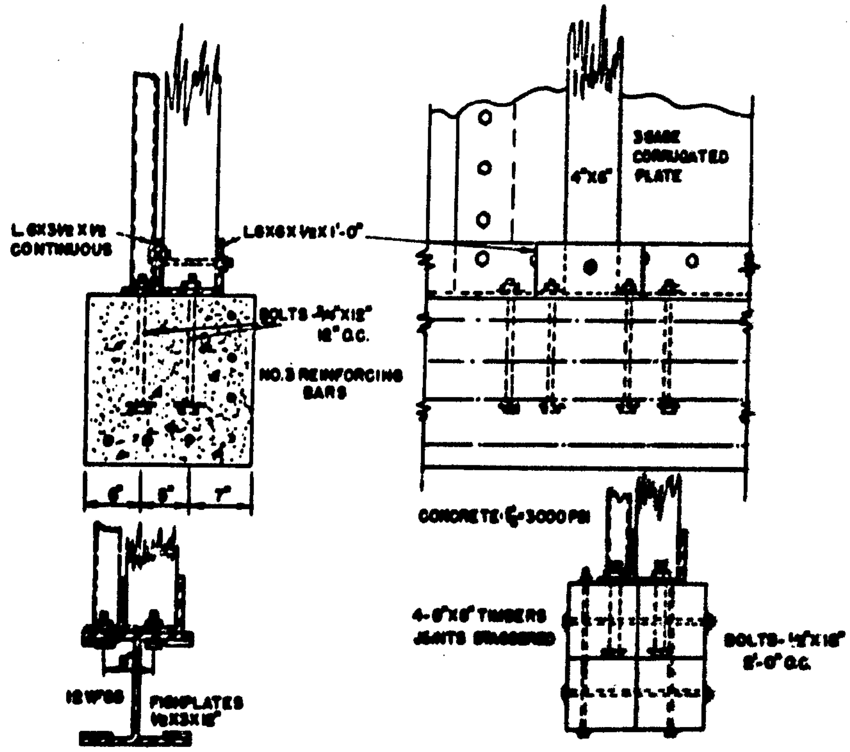


Fig. 26. End wall footing details.

end walls may be of reinforced concrete, timber, or corrugated steel. Corrugated steel or wood sheathed end walls, in general, would require a steel or timber framing. Wide spans of timber may also be framed. End walls representing all of the types mentioned here have successfully withstood nuclear blast surface side-on overpressures of over 100 psi. These empirical results have been used to design end walls illustrated in Figs. 18, 29, 30, 48, 51, and 53. The end wall in Fig. 18, employed with a circular concrete structure, may be used with identical placement and bracing for corrugated steel circular and cattle pass sections up to 8 feet in diameter. The entire deadman-supported end wall (Fig. 24), for structures with radii of 10 feet or less may be employed as a structure-supported end wall with similar bracing, sheathing, deadman, footings, and tie rods for structures with radii of 13 feet or more.

Structures of 12½-foot radius have been thoroughly tested employing structure-bearing, timber-framed, and deadman-supported end walls (Fig. 27). Other end wall deadman details are shown in Fig. 28. Similar end walls may be used for rectangular and

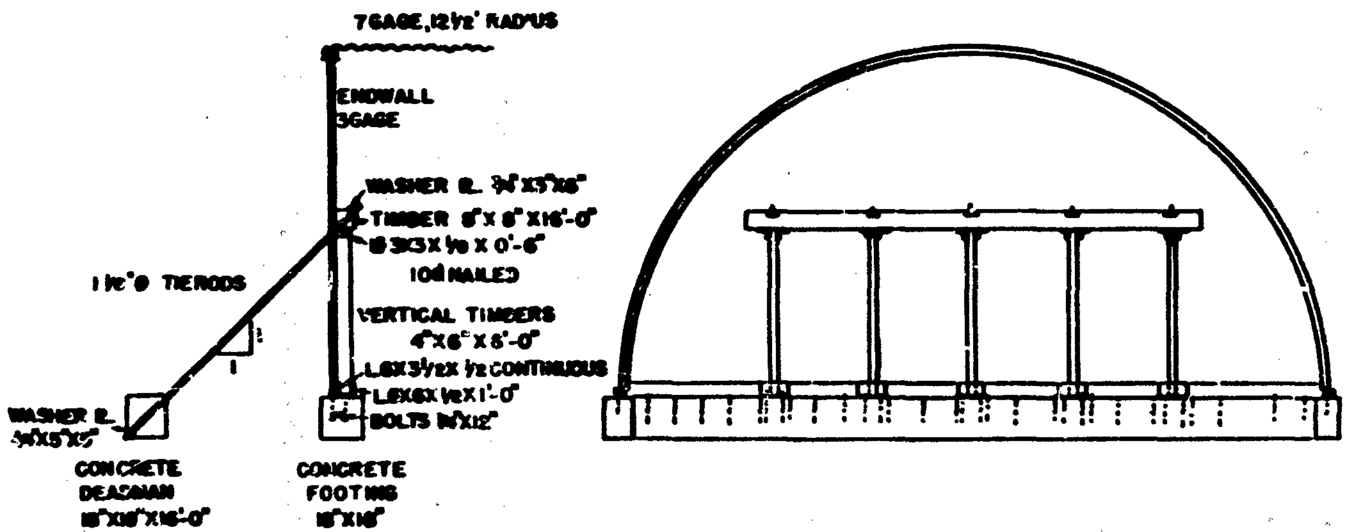


Fig. 27a. Structure and deadman-supported end wall, structures up to 12½-foot radius. Stock parts for Navy stock 12½-foot radius ammunition storage magazine; end wall, frame, and deadman.

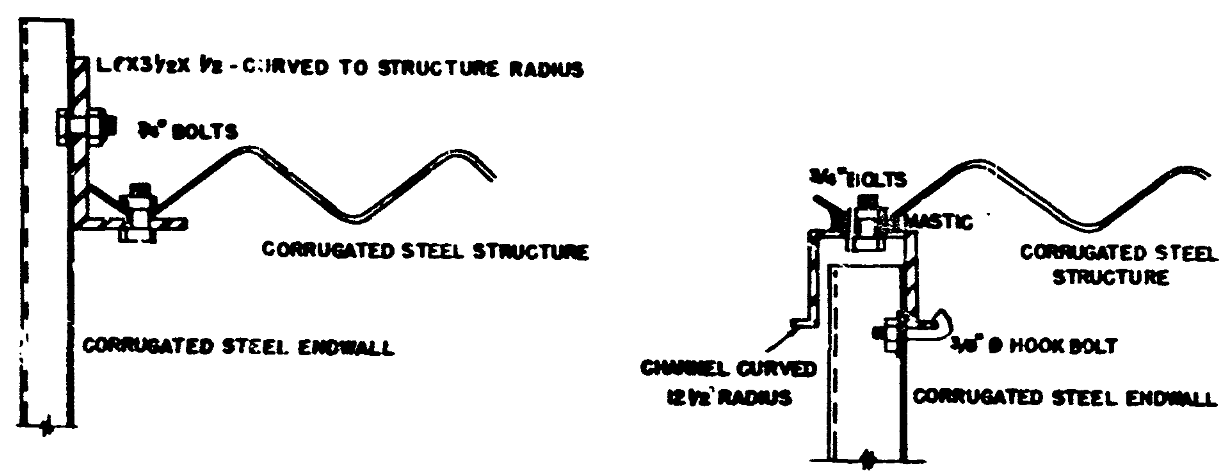


Fig. 27b. Structure and deadman-supported end wall, structures up to 12½-foot radius. Stock parts for Navy stock 12½-foot radius ammunition storage magazine; stock and alternate structure, end wall connection details.

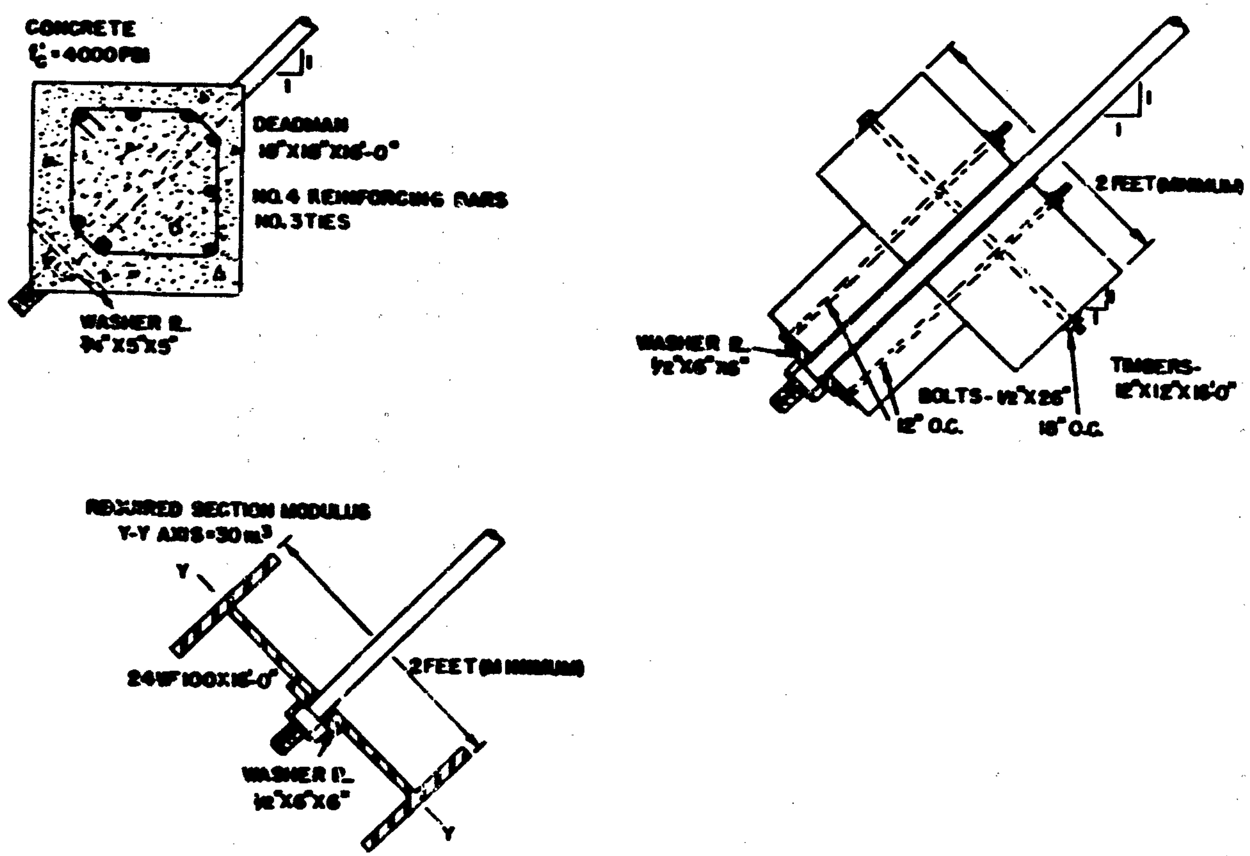


Fig. 28. End wall deadman details.

semicircular structures with heights or radii equal to or less than 12½ feet. A double horizontal beam frame with two banks of tie rods (Fig. 25) should be used in structure-bearing end walls for rectangular structures with heights 13 feet or more.

Selection from the designs presented for deadman-supported and structure- and deadman-supported end walls for a given basic structure design depends on the cross sectional area of the basic structure; the material of construction; additional secondary design requirements placed upon the end wall (such as provision of a means of access); and materials available for end wall construction. A summary of the designs and their principal use is presented in Table IV for selection guidance.

c. Earth at Angle of Repose. Basic structures with low heights and certain entrance configurations may employ an end wall which consists of compacted earth placed at its angle of repose. This type of end wall has the advantage of providing a means of entrance to the structure free of shear and differential settlement forces and avoids the use of a constructed end wall. Disadvantages are related to the undesirability of an open earth face and the necessity for a much longer basic structure to provide required floor space. The earth end wall has not been tested under overpressures from nuclear detonations, but with its use some of the adverse effects that rigid end walls have had on basic structures in such tests would be avoided.

Design of the end wall is to be accomplished in the field by determining the angle of repose of the earth (dry) to be employed. This is the end wall slope, even though batting or sandbags may be used to provide a dry wearing surface. The top of the earth fill must extend at least 2 feet inside of the end of the structure. This type of end wall is shown in Fig. 49. Conditions which would favor the use of such an end wall may be the absence of suitable construction materials; time limitations coupled with a basic structure of prefabricated and rapidly placed material; necessity for avoiding shear forces on utility lines entering the structure; or construction by tunneling instead of cut-and-cover methods.

11. Entrance Configurations. Entrance configurations are included as components requiring design consideration exclusive of the materials of construction or the type and foundation of closures. Materials are selected from the basic structure section presented. Therefore, the plans provide some illustration of the structure design procedures. The principal consideration in the design of entrance configurations is the extremely high reflected pressure that is developed upon surfaces that obstruct the passage of the shock wave upon the ground surface. Figure 1 illustrates the amplification

Table IV. End Wall Selection Guide

Structure Material	Maximum Span or Diameter (ft)	Suitable End Walls (par. 10)	Remarks
Reinforced concrete, timber	Any	1. Structure (and deadman) supported (a) Horizontal timbers (Fig. 18) (b) Sheathing on frame (c) Reinforced concrete 2. Deadman supported (use span-end wall schedule for corrugated steel arch) 3. Earth at angle of repose	Reinforced concrete end walls should be designed as one-way (horizontal) slabs. Deadman support should be considered to reduce unsupported span for wider structure.
Corrugated steel (circular, cattle pass, arch)	= 8	1. Structure supported (Figs. 18, 29, and 30) (a) Horizontal timbers (b) Horizontal timbers with bracing (c) Wood or corrugated steel sheathing (d) Reinforced concrete 2. Earth at angle of repose (Fig. 49)	Timbers forming one end wall may have depth of section varying with span.
	= 12	1. Deadman supported 2. Structure and deadman supported (Fig. 27) 3. Earth at angle of repose.	Use frame illustrated in Fig. 27. Let sheathing lap structure.
	= 20	1. Deadman supported (Fig. 24) 2. Structure and deadman supported (Fig. 27) 3. Earth at angle of repose	Let sheathing lap structure.
Corrugated steel (circular, arch)	= 25	1. Deadman supported (Fig. 25) 2. Structure and deadman supported (Fig. 27) 3. Earth at angle of repose	
	= 25	1. Deadman supported (Fig. 25) 2. Structure and deadman supported 3. Earth at angle of repose	Use frame illustrated in Fig. 24.

NOTE: Suitable end walls are listed in the order in which their use should be considered. Ranking is based on ease of construction and nature of probable response in failure caused by extreme overpressures.

of overpressure upon reflection from surfaces at varying angles of incidence. Entrances that have the closure flush with the horizontal surface avoid the development of pressures greater than those of the side-on overpressure. Variation occurs when an entrance closure may not be completely flush to the surface because of design and mechanical considerations. For example, the hinges and ribs on the closure may reflect the blast wave so that the resultant average pressure on the closure is greater than the side-on overpressure. Some modifications made to tested closures in paragraph 12, "Blast Resistant Closures and Frames," are based on the avoidance of localized reflected pressures. In addition, it is desirable to have vertical entrance so that the passage to the closure may be normal to the ground surface. Structure close to the surface should be kept to the minimum length possible. The entrance passage is primarily subjected to horizontal (lateral) earth pressure loadings which are on the order of one-fourth to one-half the magnitude of the overpressure developed on a horizontal surface at the same depth.

Other considerations are necessary when a horizontal entrance section is specified. Under these conditions, an entrance configuration must be employed so that the basic structure is fully buried (for example, a ramp entrance) or has an earth berm sufficient to create fully buried conditions. Furthermore, the initial entrance section from the closure requires special design considerations for reflected overpressure developed upon the berm. Maximum earth cover over this section is desirable. The use of vertical shafts and lifting equipment, therefore, should be thoroughly investigated prior to the design of any upstanding closure and accompanying horizontal passage.

Blast closures in series are desirable in personnel shelters. Reliance on a single closure could be disastrous if it were open at the arrival of a blast wave. Single closures should be employed only on nonpersonnel shelters or on emergency shelters where the occupants of the shelter are well drilled in structure utilization. A high degree of training must be maintained, even with the use of two personnel blast closures, to ensure continuous protection. Two blast closures are ineffective unless a signal procedure is planned or a guard is present to see that no more than one closure is ever open at one time. In addition, a double closure configuration could provide a well-isolated radiation decontamination area. Such considerations should be taken into account when a selection is made from the various entrance configurations.

Different entrance configurations, with the designs to be employed in the selection of the materials of construction, are presented here. The selection of a specific entrance configuration depends on the type of structure and the materials available. The degree to which the entrance configuration selection is dependent on structure use is such that entrance configuration is treated both as a structural component and as a utility to be selected directly from the structure utilization guide.

a. Vertical Tube to Horizontal Passage. The greatest resistance to nuclear blast overpressure is obtained by the use of a blast closure flush with the ground, in conjunction with a small-diameter vertical tube passage, leading to a horizontal circular one. This entrance configuration has been tested using various structural materials at overpressures up to 150-psi side-on overpressure without damage. The configuration shown in Fig. 29 is an adaptation of the tested designs to provide a transition between the vertical tube and the horizontal passage. This plan permits more rapid entry or exit than is possible with the designs tested in the field. A variation of this design and one which provides an air lock is shown in Fig. 30. The illustrated configurations are examples. Their dimensions may be varied to permit additional use of the horizontal section or to allow passage of larger items through the vertical tube. Selection of the end wall for the horizontal section should be the same as that described for the basic structure in the preceding section.

Variations from the illustrated section may be made by the substitution of circular prefabricated concrete for either horizontal or vertical sections or by the use of timber, such as is shown in Figs. 20 and 22. Small-diameter or specially designed basic structures may employ a vertical section which enters directly into the structure. Such a vertical tube would be as shown in Fig. 29. Use of this tube, however, is undesirable in any personnel shelter because of the high initial radiation permitted by the configuration. A variation of the safety steps could be a straight steel bar placed as shown for the emergency exit (Fig. 32). The steps may be placed after construction and secured by nuts or welds.

b. Vertical Shaft to Horizontal Passage. A vertical shaft is the best blast resistant means of providing entry to a protective structure for passage of bulky equipment. If possible, a large rectangular or circular shaft should be used in lieu of a horizontal entrance from the surface. A large pressure reduction is obtained for blast closure design by not using a horizontal entrance. A suitable rectangular vertical shaft construction is illustrated in Fig. 23. Use of such sections in conjunction with a horizontal passage is shown in Fig. 31. The horizontal section may be of any compatible design or material. A corrugated steel vertical shaft is shown in the design of an air filter-generator alcove (Fig. 48).

c. Horizontal Entry from Surface. A horizontal entry leading by a passage or ramp to the basic structure is inadvisable. Such an entry should be considered only when the utilization

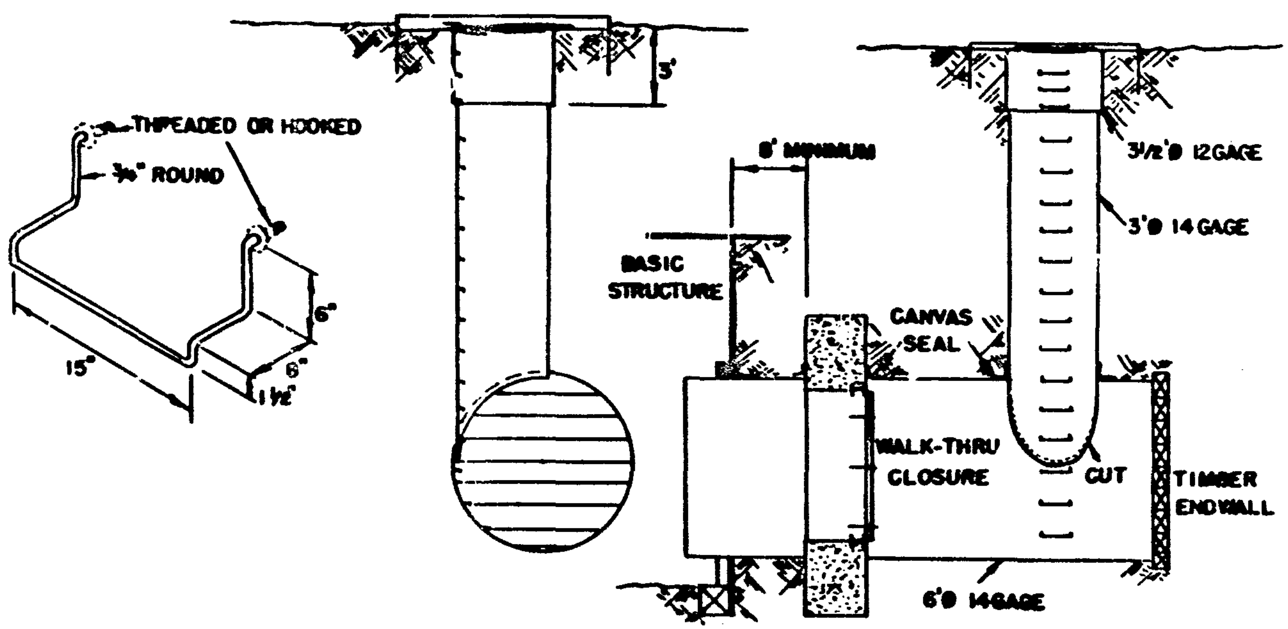


Fig. 29. Vertical tube to horizontal passage entrance configuration. A designed personnel hatch on a concentric ring foundation is shown here.

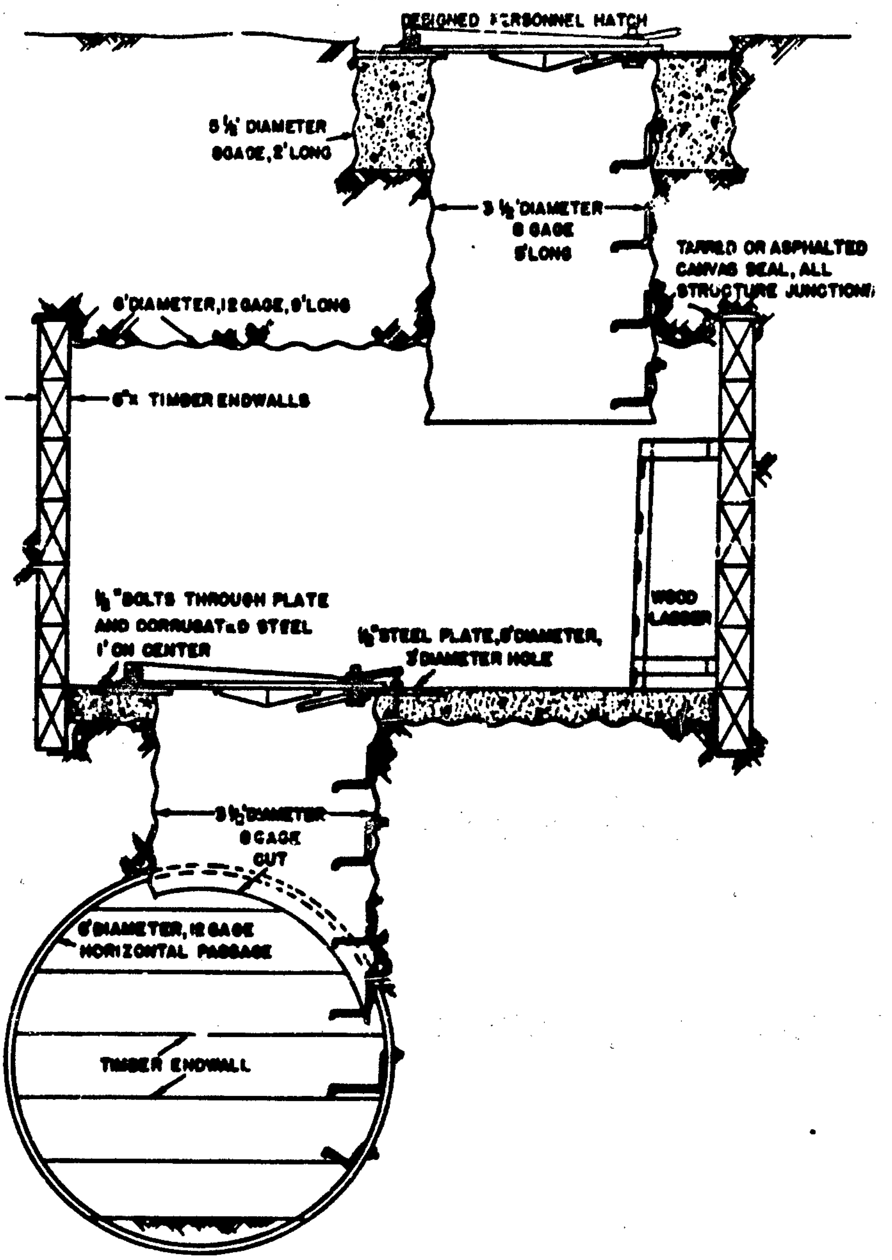


Fig. 30. Entrance configuration with a separate air lock.

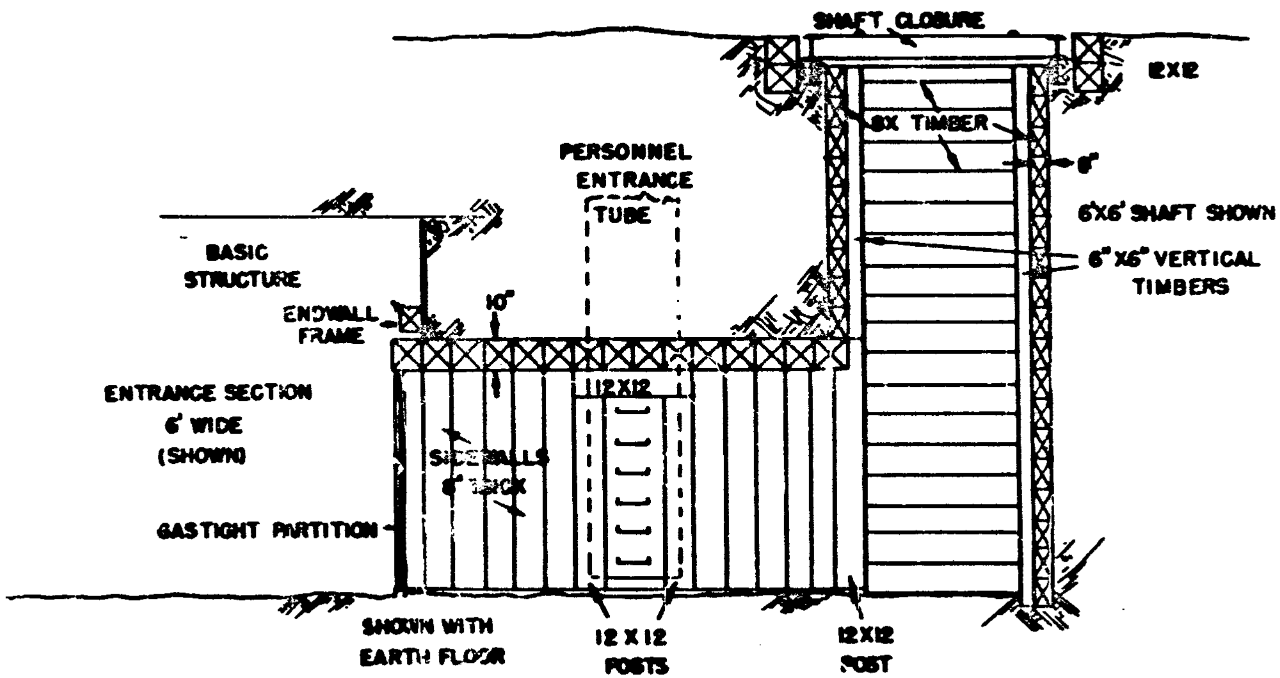


Fig. 31. Timber shaft and passage entrance configuration. A separate personnel entry tube adjacent to the horizontal passage is shown here.

requirements of the structure require wheeled vehicle access. Exterior walk-through personnel hatches of a size sufficient to withstand the probable reflected overpressures are so massive that hand operation is extremely difficult. The doors would weigh 600 pounds or more and would be subject to jamming or blocking as a result of blast action or accumulation of debris.

For the situations where the use of a horizontal entrance is unavoidable, the entrance section must be designed to withstand the reflected pressures developed on the berm flanking the door. In addition, the thrust of the door frame foundation must be resisted either by the entrance section or by a separate bearing frame. Except for reinforced concrete sections, it is recommended that a separate bearing frame be used.

The increase in pressure caused by reflection on a vertical face in the line of the blast wave is indicated in Fig. 1. For 50-psi side-on overpressure, a reflected pressure of about 200 psi may be developed. The selection of circular or arch corrugated steel sections from the design graph (Fig. 11) should be based on the reflected overpressure. The graph is valid for extension of the side-on overpressure scale beyond 100 psi, the limit shown. A reading for 200 psi could be made by "folding" the vertical scale. In operation, a plot could be made for 200 psi divided by 10 or 20 psi, for the applicable radius structure. A 45° line would then be drawn to the right and down. At the intersection with the 10-psi line, an ordinate would extend the point to the 100-psi line to specify the required thickness of steel. For a horizontal entrance from the surface, the cattle pass section should be designed using as the radius for entry into the chart, the actual radius of the long arc segment at the side of the section (Fig. 13 and Table I).

Illustrations of horizontal entrance configurations are given in connection with door frame-supporting foundations (Figs. 44 and 45). The increased pressures from reflection of the blast wave necessitate use of small cross sectional passage areas and encourage the use of light, hand-pushed rail cars on removable track and similar equipment to transport heavy objects.

The general vulnerability to initial radiation of a straight-in entrance section from the ground surface makes the basic structure unsuitable as a personnel shelter. The high risk of jamming a relatively large door requires that a structure employing such an entrance possess a separate vertical entrance.

d. <u>Entrance through an Exposed End Wall</u>. There are a few reasons for which direct entrance from the surface into the structure through an exposed end wall may be necessary. Space limitations or construction of storage for high-priority hardware in rock may require such an installation. Otherwise, a separate and independently acting entrance passage to the structure should be used. Principal adverse effects of an entrance through an exposed end wall are the extremely high initial radiation within the structure resulting from the relatively poor shielding of the closure; the large longitudinal load with which the end wall bears on the structure under blast loading; and the problems inherent in a door, frame, and foundation subjected to the reflected blast overpressures. The design of an exposed end wall has not been made a subject of this study; however, Figs. 38 and 39 for the massive door and an exposed concrete wing wall show some of the problems involved in this type of entrance.

e. Filled Tube Emergency Exit. Any structure may be provided a blast proof emergency exit by the use of a corrugated pipe filled with sand. Such installations have been tested with success at high nuclear blast overpressures. Illustrations of this type of exit are given in Figs. 32 and 33.

Although corrugated steel is recommended, a blast resistant emergency exit may be built with precast concrete pipe or timber shafts filled with sand.

In operation, the emergency exit provides a means of escape without requiring full-scale excavation. Personnel trapped by partial failure of the principal entrance, for example, by jamming or blocking of the closure may, with some effort, escape from the structure. The sand is shoveled from the lower end of the emergency exit to permit gravity evacuation of the column of sand. Care should be taken in selection of the fill to prevent packing within the column which would hinder removal. Also, silty fines could foul the air within the shelter during the removal operation. The cross sectional area and length should be kept to a minimum to reduce the amount of material to be removed. A ladder or steps should be placed within the pipe to ensure exit, to avoid the need to store a ladder in the shelter, and to provide a means of access to material stuck in the tube during evacuation. The thickness of corrugated steel is not critical if the fill material is well tamped. Therefore, the lightest gage available may be used. A frangible waterproof cover should be placed over the exterior end of the exit. All occupants of the shelter must be acquainted with the location and operation of the emergency exit, as they must be with all of the operating and emergency equipment of any shelter.

12. Blast Resistant Closures and Frames. As with the entrance configurations, the orientation of blast resistant closures is critical in determination of required design overpressure. For example, in a 50-psi side-on overpressure region, a vertical exposed face may be subjected to 200 psi upon shock wave reflection, while a horizontal

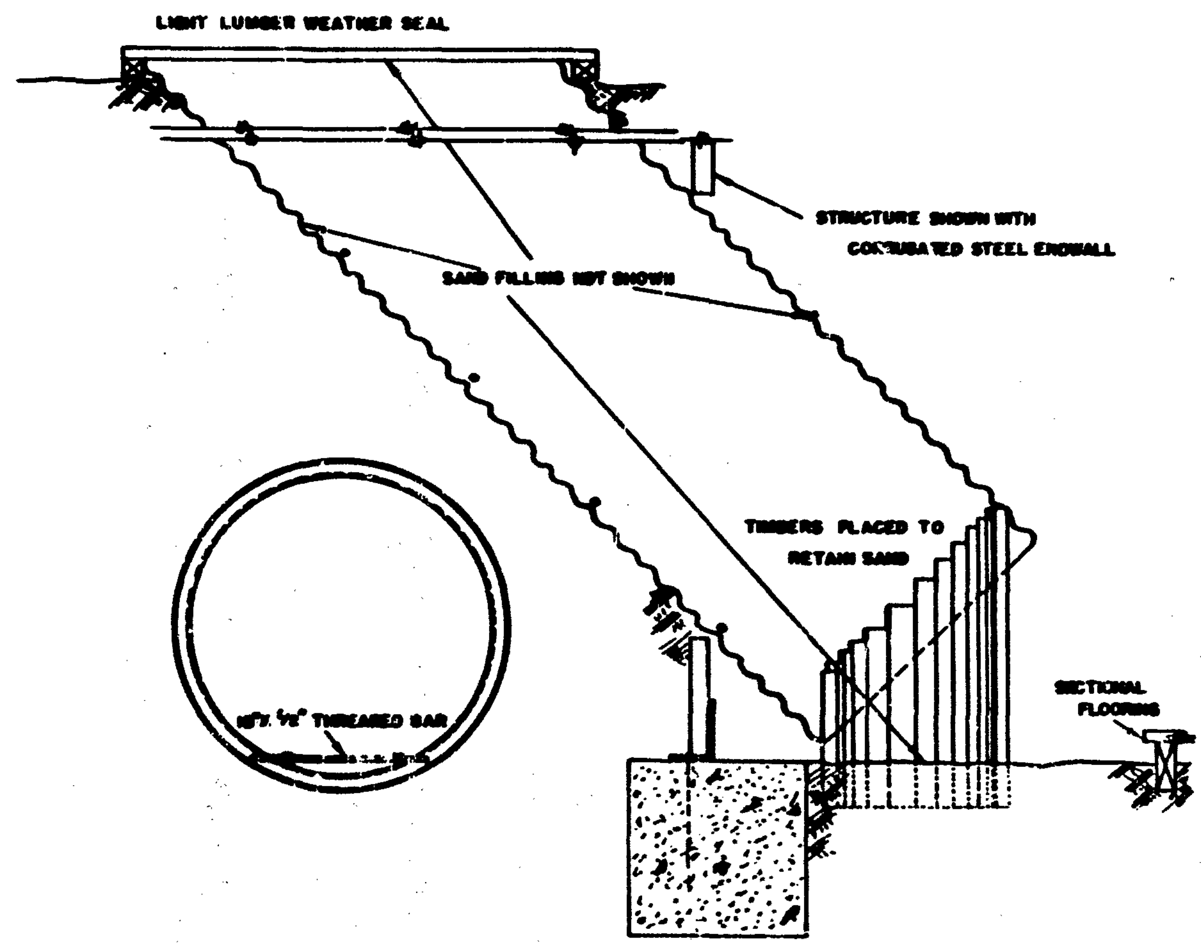


Fig. 32. Corrugated steel emergency exit.

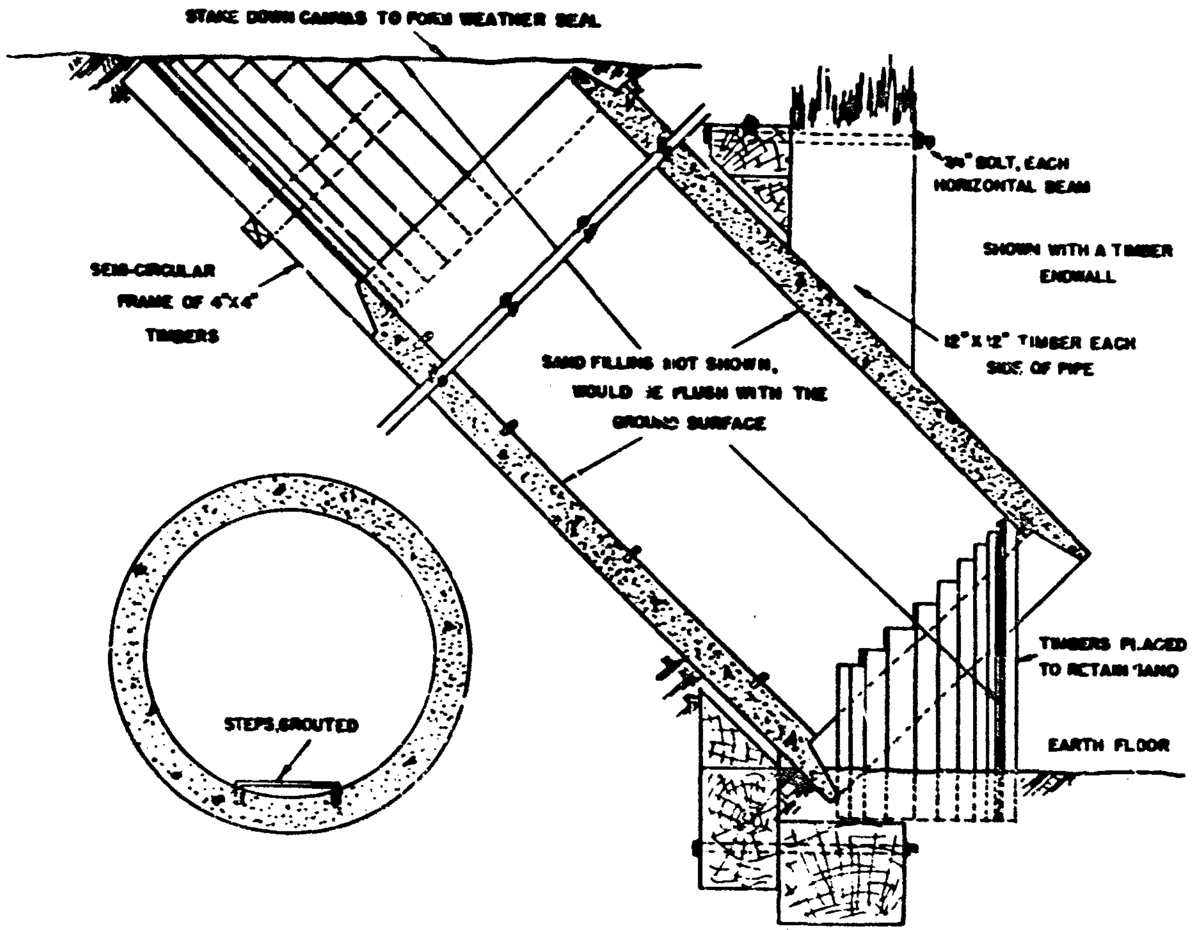


Fig. 33. Precast concrete emergency exit.

face flush with a level surface must withstand only 50 psi. Exposed blast closures are one of the principal sources of radiation within a structure. The air-supply system and openings from a bent or loose fitting closure are the main source of induced or fallout post-shot radiation. A horizontal passage leading directly from a walk-through or larger door into the basic shelter area may allow lethal dosages of instantaneous radiation to occur within a structure even with a satisfactory earth berm shielding the remainder of the installation. Similarly, high instantaneous radiation may be admitted directly to a structure through a vertical entrance with a flush blast closure. This source of radiation is reduced most effectively by the use of small blast closures, by small-diameter passages, and by offset, or otherwise indirect, entrance configurations. Increasing the thickness of the blast closure is not a satisfactory shielding solution as the increase in shielding is insignificant, and the increase in weight is prohibitive for satisfactory operation. Closures presented in this section are designed solely for overpressure resistance. Those for flush placement over a vertical entrance or for backing up such a closure have been designed for 50 psi. The walk-through or drive-through closures have been designed for 200 psi (Fig. 1). Where possible, designs have been employed which have been proved by nuclear blast tests upon similar or identical closures. These tests have shown that adequate closures (for blast resistance) are feasible. As can be noted from the presented designs, the span of the closure and its orientation are extremely critical. The required section modulus increases as the square of the span and proportionally to the applied pressure. Means of reducing the required span or the overpressure (for example, by use of a vertical shaft) should be examined thoroughly, with considerations given to possible disassembly or placement of bulky equipment during construction and to reduction of radiation in a personnel shelter.

a. Designed Personnel Hatch. The best blast closure is a small span hatch for vertical entrance. Such a closure is used in conjunction with the entrance configurations described in the preceding section. A designed hatch, similar to one proof tested during high explosive blast tests and employing standard structural shapes and steel plate is illustrated in Fig. 34. The steel sections shown can be varied, provided the section moduli of substituted shapes are not less than those shown or the steel used does not meet standards less than those of ASTM A-7 (U. S. Manufacturing Standard for intermediate grade structural steel).

A personnel hatch should be employed at the ground surface and the backup closure to form an air lock. Installation may be with horizontal or vertical orientation in the latter application. Placement within a horizontal passage (Fig. 35) should be made with the hinges oriented for doorlike operation with gravity holding the door open except when secured by the locking mechanism.

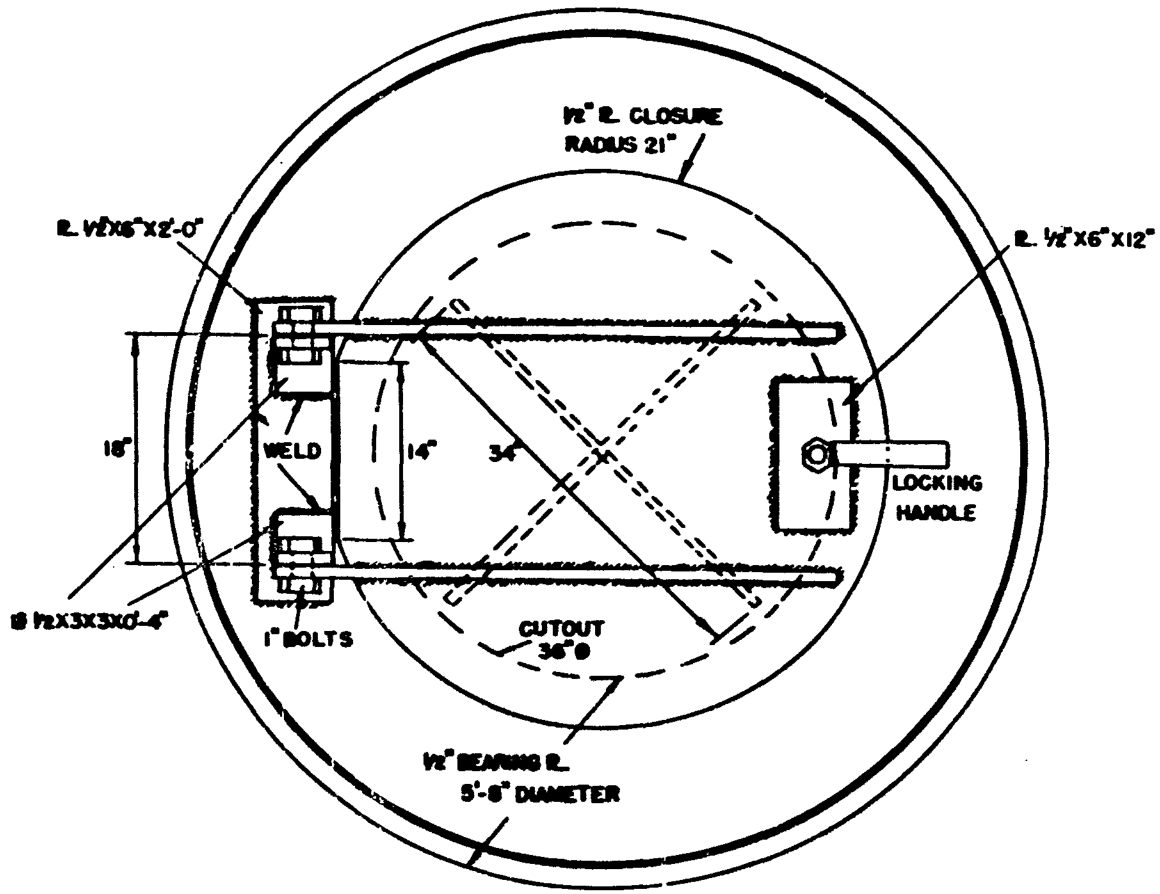


Fig. 34a. Top of designed personnel hatch. A tamped earth-filled concentric ring foundation is shown here.

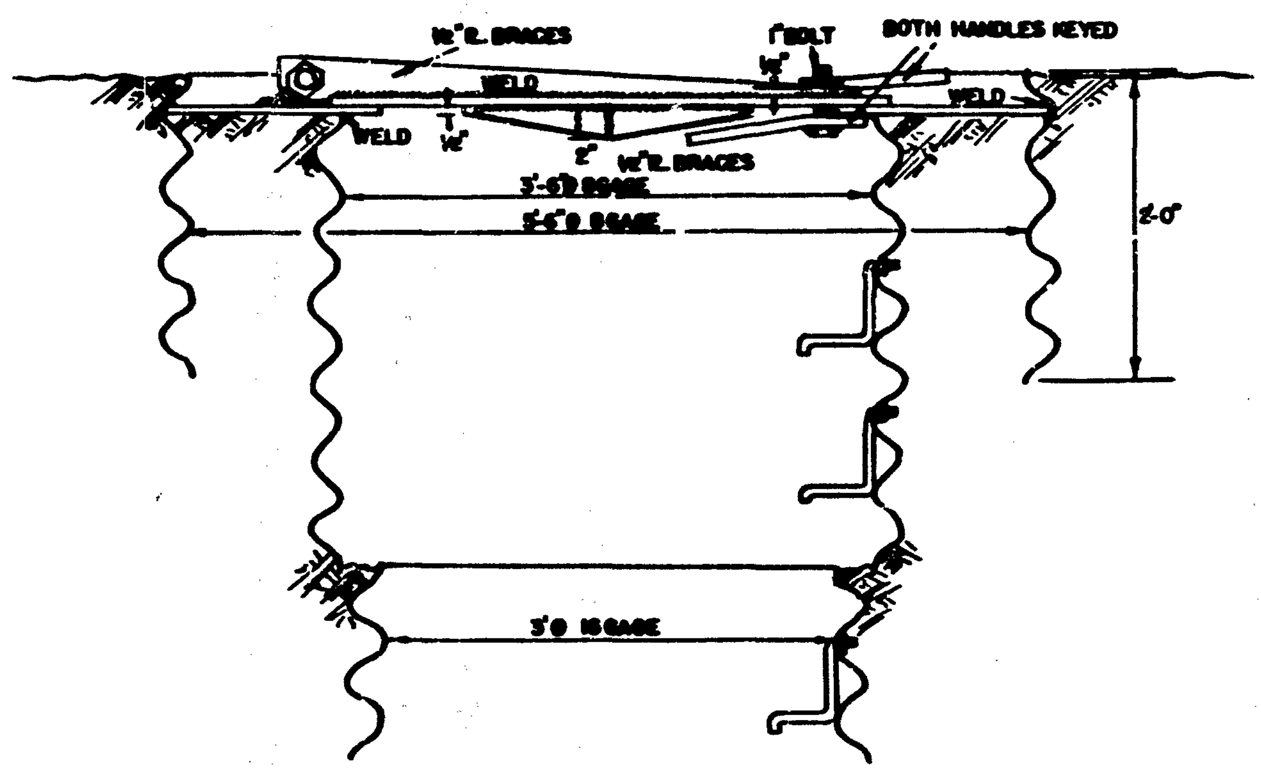


Fig. 34b. Vertical section of a designed personnel hatch. A tamped earth-filled concentric ring foundation is also shown here.

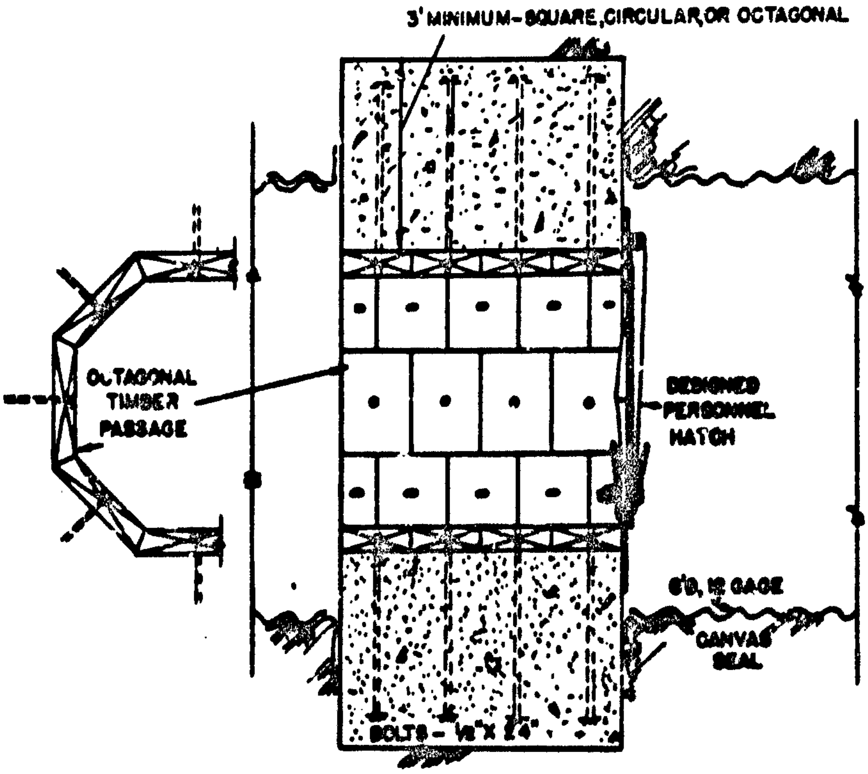


Fig. 35. Designed personnel hatch in a horizontal passage; horizontal section.

A second hatch within a separate chamber and near to the outside closure facilitates the maintenance of a positive closure by means of a guard placed between the two installations. Placement of the second hatch within the horizontal passage section would provide a greater area for use in radiation decontamination and would permit the passage of larger groups entering or leaving in each cycle of closure operation. Two guards and posted signal procedures, such as raps on the closure, should be considered for achieving rapid personnel passage while continuous blast protection is maintained.

b. <u>Closure for a Rectangular Shaft</u>. A shaft forms the best means of entry for bulky objects into a structure on the basis of radiation and structural blast resistance considerations. The closure shown in Fig. 36 or modifications to this design permits passage of large equipment through a vertical shaft. Use of light

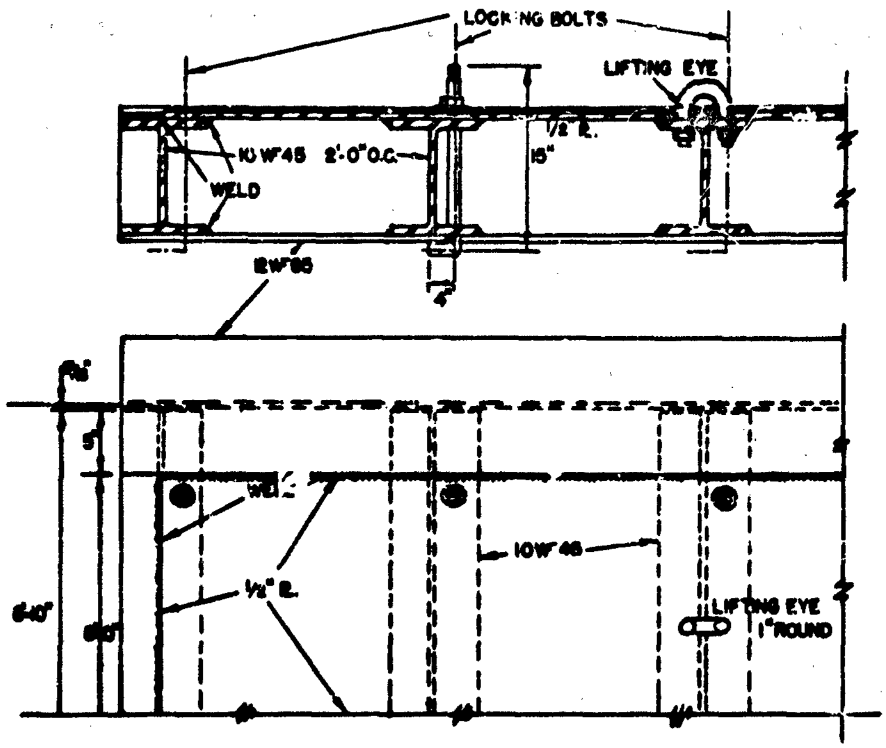


Fig. 36. Steel lift-off shaft closure.

rail equipment in the horizontal entrance passage at structure level would facilitate the movement of such equipment into the structure. The crane, wrecker, or other lifting device used to raise or lower the equipment in the shaft could similarly be used to place and remove the closure. Design of the closure is based on the selection of an allowable fiber stress half that of ultimate stress and about two-thirds of the dynamic yield stress. A finite rise time as a result of gradual load application may be assumed for a blast overpressure of 50 psi. Shock propagation velocity at 50 psi is less than $2\frac{1}{2}$ feet per millisecond, and the computed period of the fundamental mode of vibration for the designed shaft closure is approximately 1 millisecond. Specific values used in the design were a maximum fiber stress of 30,000 psi and a uniform load of 50 psi. The resultant section modulus was 2 in.^{3} per inch width of closure for the 8-foot span. Variation in required section modulus resulting from the use of a different span may be made by employing the following relationship:

$$S = 2\left(\frac{\text{span in feet}}{8\ \text{feet}}\right)^2$$

where S is the revised section modulus for a section of ASTM A-7 steel. The section modulus can be corrected for the use of different materials by inclusion of the maximum allowable dynamic field stress. In this design, the maximum stress of the steel used was 60,000 psi. This approximate method of design is suggested for field use and provides a higher factor of safety for the alternate material than does the use of steel. This procedure is desirable as it allows for a more rapid rate of application of the overpressure. The fundamental period of vibration for sections of timber or concrete designed to resist pressures of 50 psi is considerably longer than for a steel section of the same span, because of the greatly increased mass and decreased modulus of elasticity. The required section modulus, S, should be varied inversely with the ratio of f'_y, the allowable maximum dynamic stress, to 60,000 psi, the ultimate stress used. The following expression based on one-way beam action may be used for design:

$$S(\text{in.}^3) = 2\left(\frac{\text{span in feet}}{8\ \text{feet}}\right)^2 \frac{60{,}000}{f'_y}$$

A similar expression for steels other than ASTM A-7 may be used by relating the static yield stresses (f_y), thus:

$$S(\text{in.}^3) = 2\left(\frac{\text{span in feet}}{8\ \text{feet}}\right)^2 \frac{33{,}000}{f_y}$$

Because of the negative pressure phase of the blastwave, the shaft closures should be designed to withstand an upward pressure of 5 psi. The negative pressure required for design (5 psi) does not vary linearly with the positive pressure, but may be considered as an upper limit to the pressure differential. The background work on which design assumptions may be based is limited, but the use of 5-psi negative pressure should avoid any failure to a structure. The field designer may justify a smaller value based on one-time use of the structure and absence of overpressure following the negative phase. Thus, although failure occurred, little internal damage is likely unless a second detonation takes place.

c. Designed Walk-Through Door. The blast closure shown in Fig. 37 is fabricated from standard rolled steel shapes and plate steel. The closure should be employed only when use of the smaller personnel hatch is not possible.

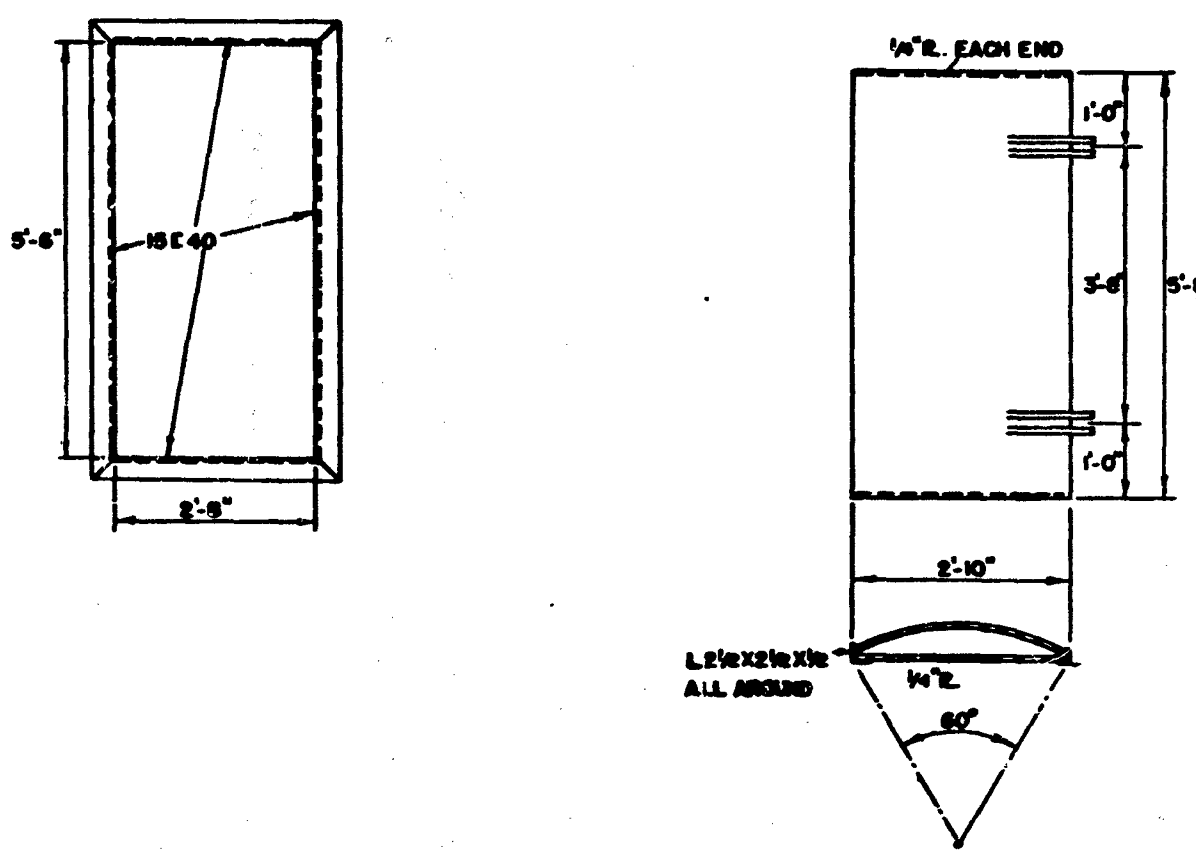


Fig. 37. Designed walk-through door.

The weight of the door, the poor radiation shielding it affords, and the excessive pressures arising from reflection of the blast wave (note in Fig. 1 that the ratio of reflected to side-on overpressure increases with increased incident overpressure) make this type of closure hard to justify. An additional advantage of flush closures is the susceptibility of upstanding surfaces to damage by fragments of conventional aerial and artillery weapons.

The walk-through door is an alternative to the personnel hatch for in-tunnel placement to back up an exterior closure to form an air lock. Furthermore, the walk-through door should be considered for situations which require a means of horizontal access where the width does not necessitate a massive drawbridge-type closure. Two doors with a removable center post mounted within the frame illustrated for the drawbridge door (Fig. 45) would be easier to operate. A thin steel arch section in the door has received limited nuclear blast testing. Several prototypes of similar design were fabricated and employed in the tunnels used for the underground nuclear test series. Qualitative experience gained in these tests, in which exposure of the blast doors to overpressures were accidental, indicated the strength of the door was greater than the strength of the frame and frame-foundation connections. A closure employing rolled steel sections to span the frame instead of an arch action was tentatively designed for similar blast overpressures (200 psi). The weight of this door was about 200 to 300 pounds in excess of the 400 pounds of the presented door design. The door is too heavy to be rapidly operated by individuals. Closures may be conservatively designed because it is desirable to have the strength of the whole dependent upon the basic structure and not limited by its lesser components. The nuclear blast tests have revealed that the closures are vulnerable to failure, and thereby, catastrophic conditions may result within an otherwise undamaged structure.

d. Massive Drawbridge Door. The massive steel door illustrated in Figs. 38 and 39 should be considered only when any other means of closure is not feasible. The design is one which has successfully withstood reflected nuclear blast overpressures of 180 psi. It is modified to provide a greater resistance to reflected pressures of 200 psi (anticipated as the maximum in the 50-psi side-on overpressure region). The door provides negligible shielding to instantaneous radiation, does not readily provide an air seal, requires a large constructive effort, and is awkward to operate. Nuclear blast tests have shown that doors which operate on rollers are subject to jamming, even though they are easier to operate in normal circumstances. The drawbridge door provides rapid opening for exit of vital equipment. It has a demonstrated resistance to the design blast overpressures.

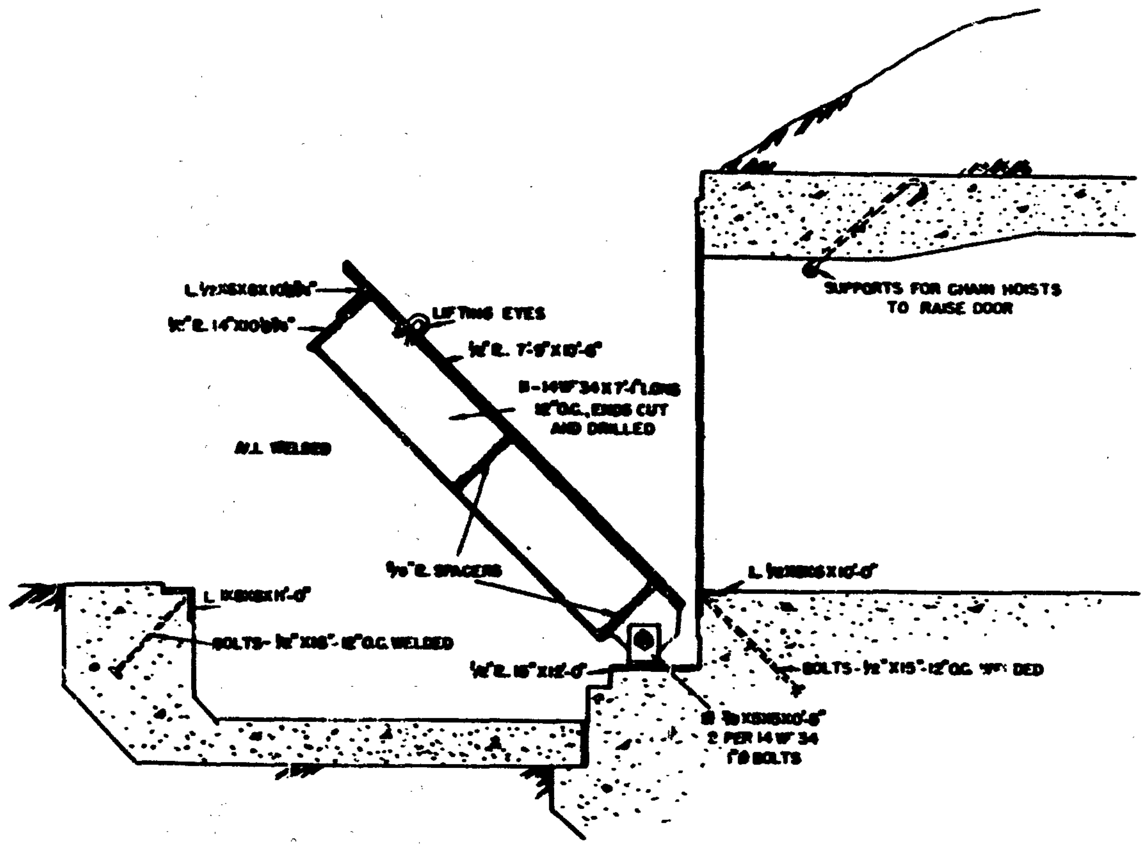


Fig. 38. Massive drawbridge door.

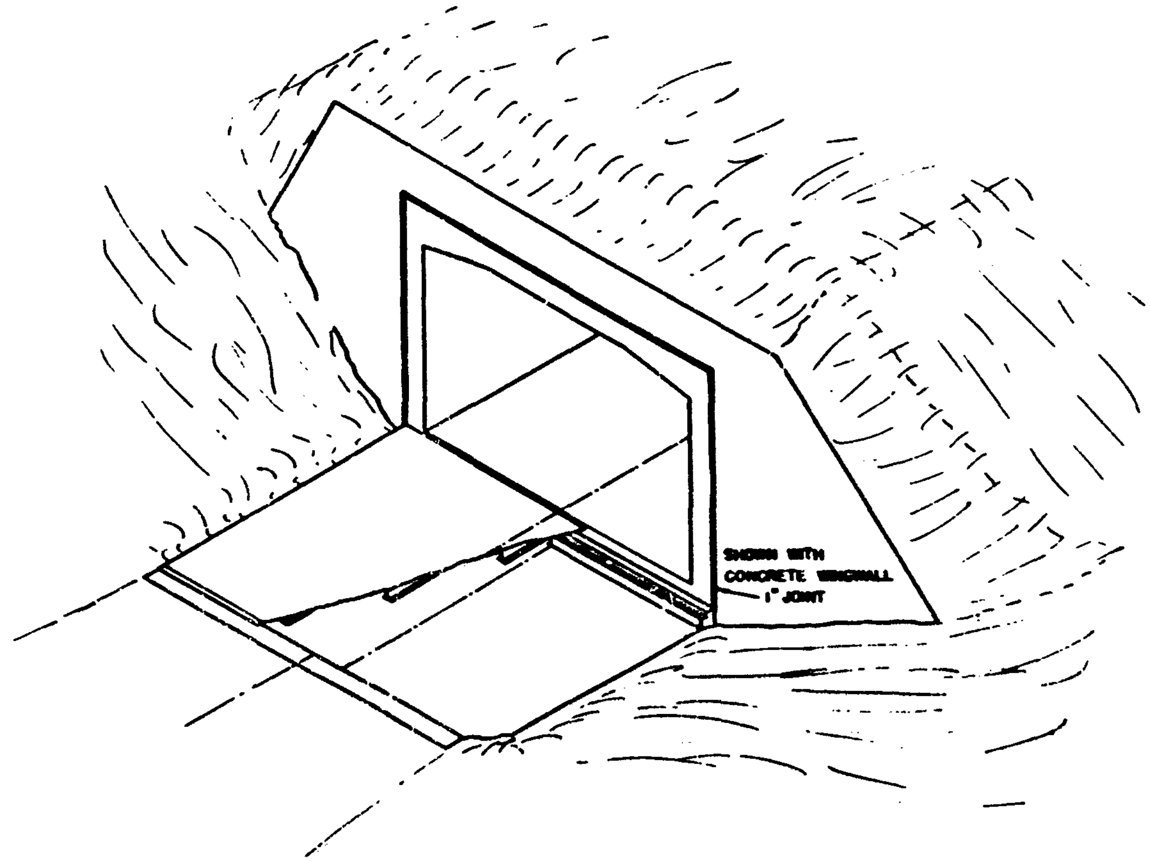


Fig. 39. Isometric view of massive drawbridge door. Note that the sides of the receiving pit are not curbed (the nuclear blast test indicated that such curbs may prevent full door opening).

13. Door Frame-Supporting Foundation. The closures and frames are designed to withstand the effects of nuclear blast overpressures in the 50-psi side-on overpressure region. The foundations for these closures are presented separately, although the order of listing is governed by closures. Little choice in frame-supporting foundation exists when the type of closure has been determined. The foundation designs are similar to prototypes which have withstood nuclear blast overpressures in excess of 50 psi. Adaptations of these designs provide equivalent resistance while employing other, possibly more rapidly constructed, materials. Thus, a choice of foundations may be applied to a specific closure. Furthermore, a specific frame foundation may be used with different closures of similar application such as those for a vertical shaft. In the foundation for a blast closure one must consider the force transmitted by the closure frame; the need to resist uplift pressures that result during the negative pressure phase; the orientation of the closure; and the danger of imposing longitudinal forces on the entrance structure. Because of its adaptability, reinforced concrete is an excellent material for this purpose. It is inherently massive and forms an excellent seal. Structural steel is illustrated as a less favorable alternate. Where feasible, the designs illustrated are similar or identical to those which have been tested under nuclear blast loadings.

a. Corrugated Steel Retaining Rings. The most readily placed foundation for the personnel hatch employs lightweight corrugated steel sections. This foundation (Figs. 30 and 34) consists of an inner ring forming the initial passage section and an outer ring providing definite retention of the bearing plate and enclosing a tamped earth or concrete-filled hollow column to avoid failure in bearing or during the negative pressure phase. The inner ring section is of larger diameter pipe than the continuation of the passage below to provide independent action in response and leeway in final alignment and height under field assembly conditions. The 8-gage steel provides adequate thickness for welding. A similar 8-gage section withstood the load generated by high blast overpressures (130 psi). Use of the heavier section as the foundation for the first 3 feet of entry passage allows the design for the lower entrance pipe to be made with no special considerations for surface placement. Concentric rings to provide a concrete form keyed to the adjacent soil may be employed for foundations for vertical shaft covers (Fig. 40). Corrugated steel for the shaft lining is economical, readily constructed, and easily designed; therefore, the use of this material is encouraged.

b. Reinforced Concrete Bearing Pad. The bearing pad illustrated in Fig. 41 is a suitable alternate and a tested means of providing bearing for the personnel hatch. A backup hatch to insure blast protection in a personnel shelter may be installed as is shown

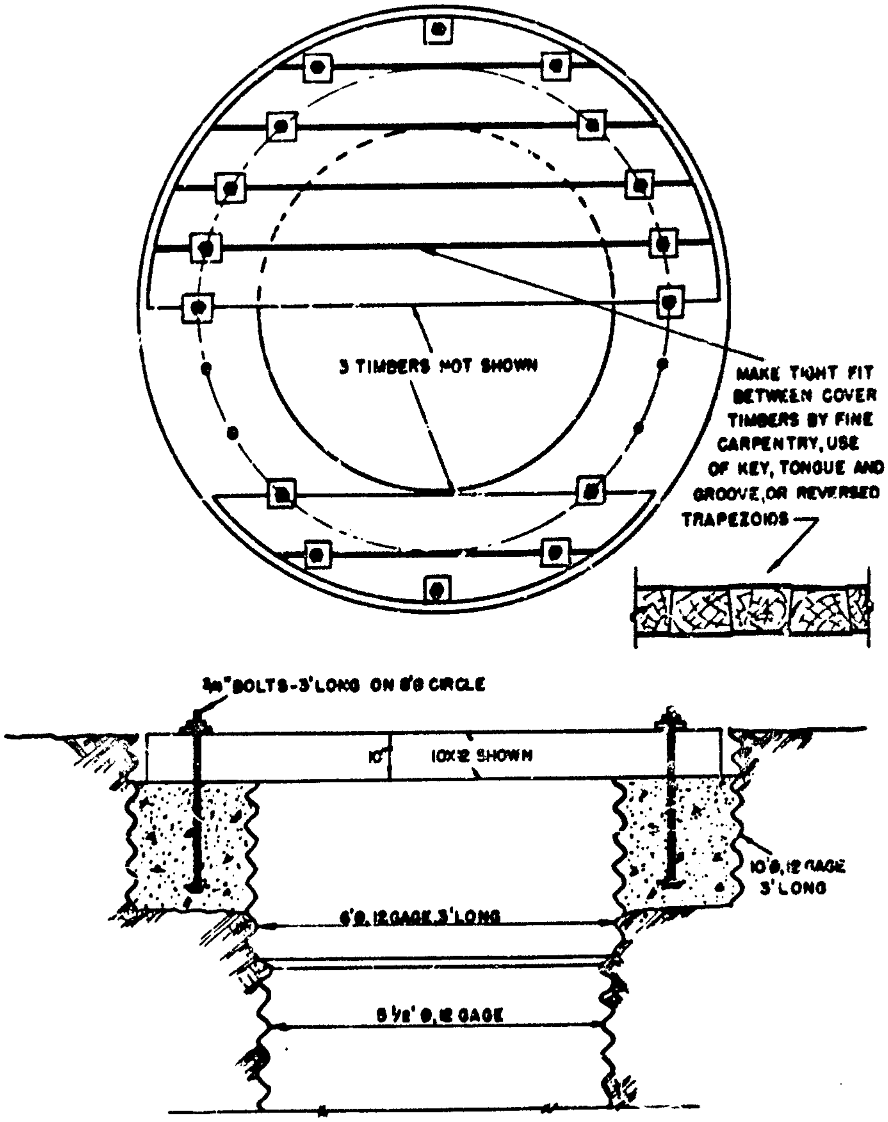


Fig. 40. Concentric ring shaft closure foundation; timber closure illustrated.

in Fig. 35. The design of the bearing pad is an adaptation of a reinforced concrete pad tested at side-on overpressures up to 100 psi with a Navy-designed prototype steel hatch.

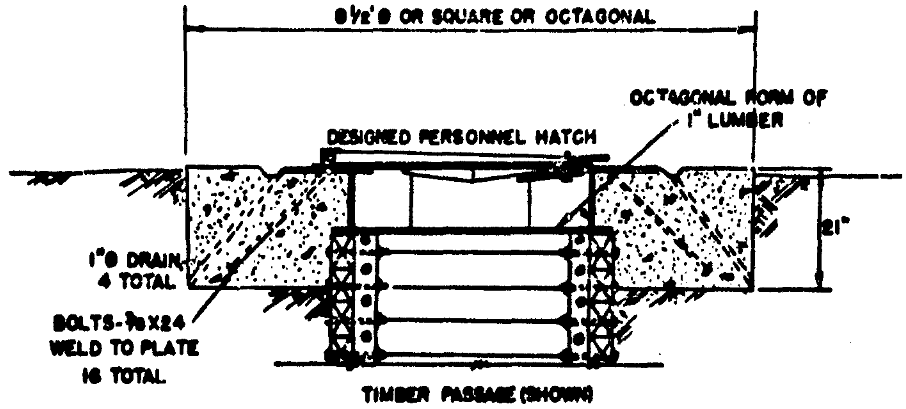


Fig. 41. Concrete bearing pad for a personnel hatch.

The walk-through door foundation for in-tunnel placement is a variant of the reinforced concrete bearing pad for placement in the vertical plane. Installations similar to the one shown in Fig. 42 were placed in the tunnels used for the underground nuclear tests series. The applied pressures and the responses of the installations were incidental to the test programs. The foundations were adequate although the design employed for the installations illustrated a weakness in the door frame and its connections. The pressures encountered, however, were sometimes imposed from the inner side, placing the full force developed by the reflected blast overpressure upon the hinge and latch which in normal design loadings would be adequate for the possible forces of the negative pressure phase.

c. Concrete Rectangular Hatch Foundation. The best foundation for a rectangular shaft hatch cover is concrete poured to form an integral unit with the frame support and the shaft lining (Fig. 43). The similarity to the concentric corrugated steel installation can be noted. An ideal form for the outer perimeter would be straight corrugated steel sections to provide a good concrete-earth key, and to maintain the quality of the concrete at what would otherwise be a concrete-earth contact. The design is intended to provide a massive foundation for spreading the vertical pressures and for resisting the upward force during the negative blast pressure phase. It should not be considered as the sole prototype but as one meeting minimum design criteria.

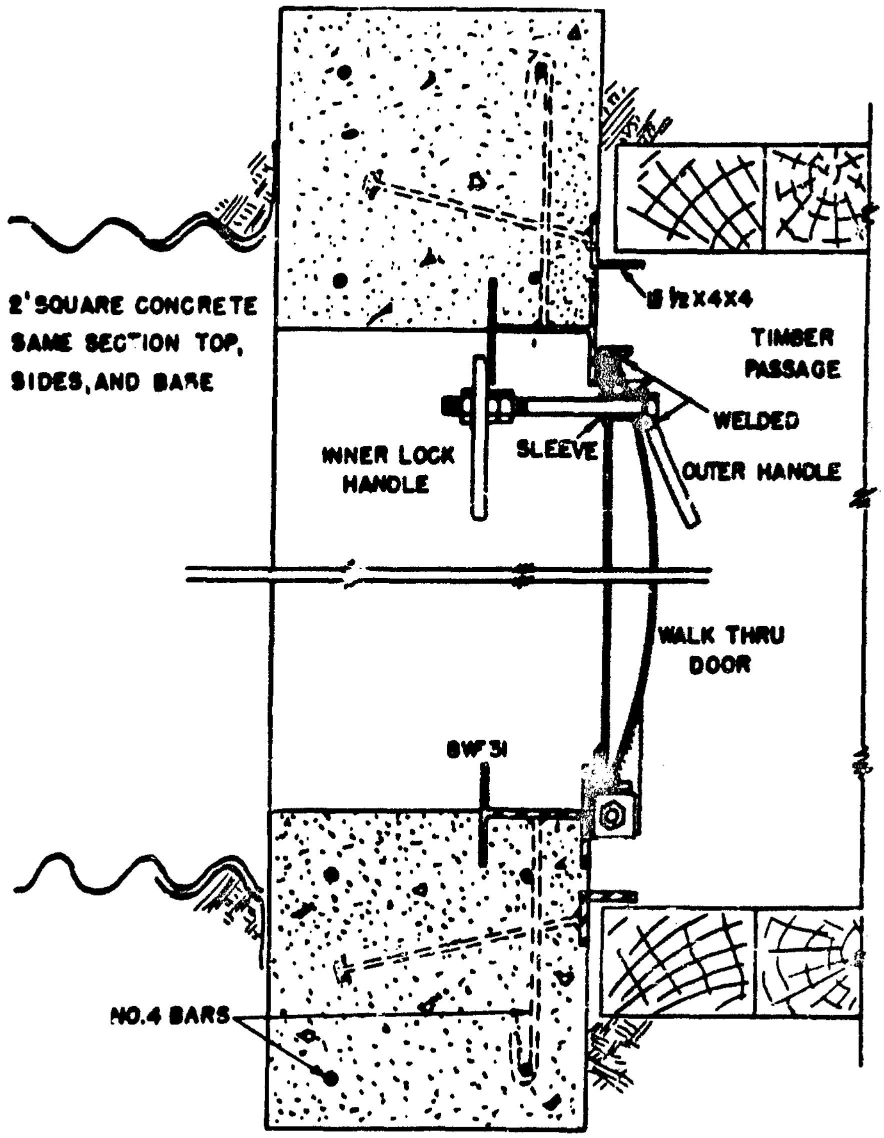


Fig. 42a. Walk-through door in a horizontal passage; horizontal section.

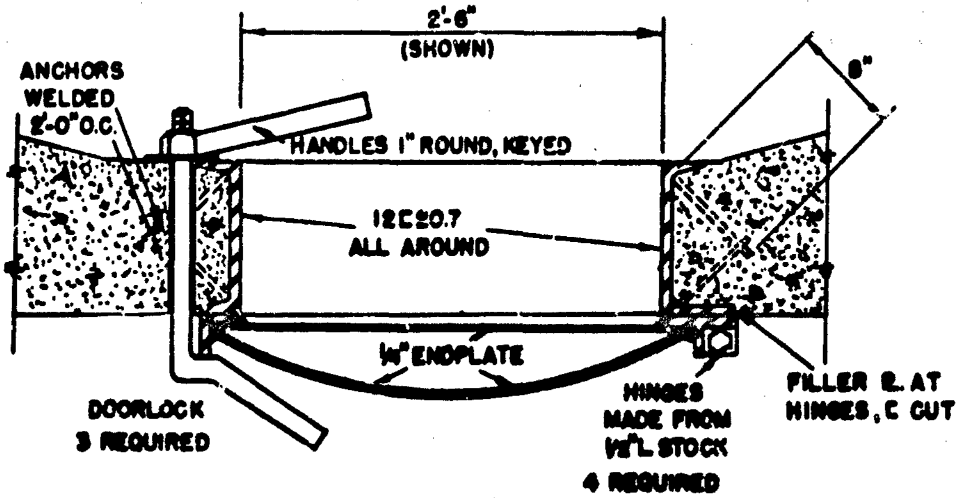


Fig. 42b. Walk-through door in a horizontal passage; alternate frame and attachments details.

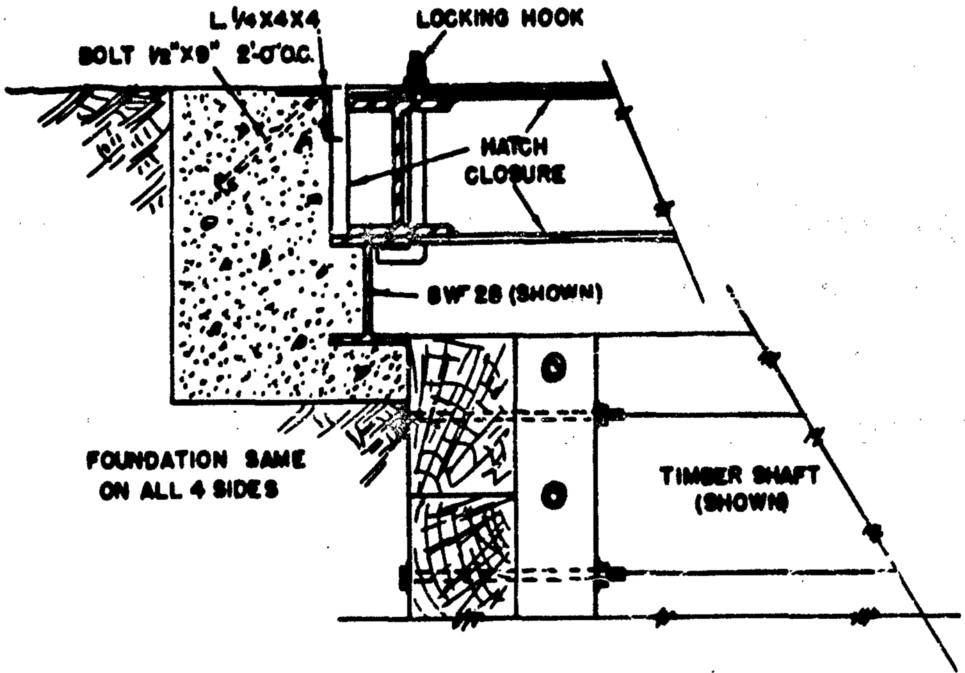


Fig. 43. Concrete rectangular hatch foundation.

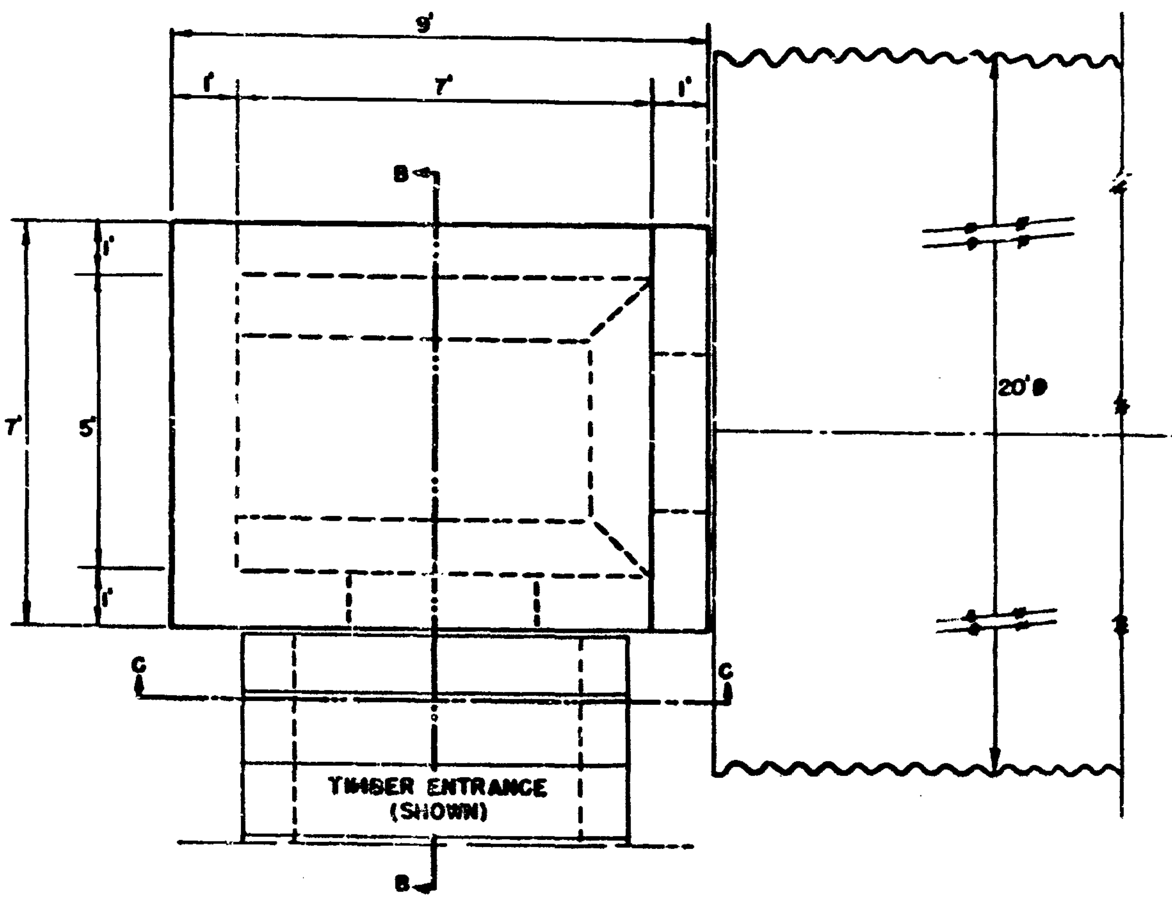


Fig. 44a. Exterior walk-through door foundation; plan with earth cover removed.

d. Walk-Through Door Foundation. An adequate foundation for an external walk-through door is shown in Fig. 44. This Navy-designed structure will withstand an overpressure of 200 psi. In the design, independent response should be provided by means of a slippage space between adjacent structural elements. A nonfragmenting, shallow retaining wall for retention of the berm should be used to avoid blocking the closure with fragments, an occurrence which has been noted with some reinforced concrete ramps and retaining walls. A severe problem is the great overpressure magnification that can take place at corners and interior junctions of plane surfaces. As illustrated, sandbags or a sand ramp may disrupt this effect and reduce the possibility of failure at the lower sill section of the foundation.

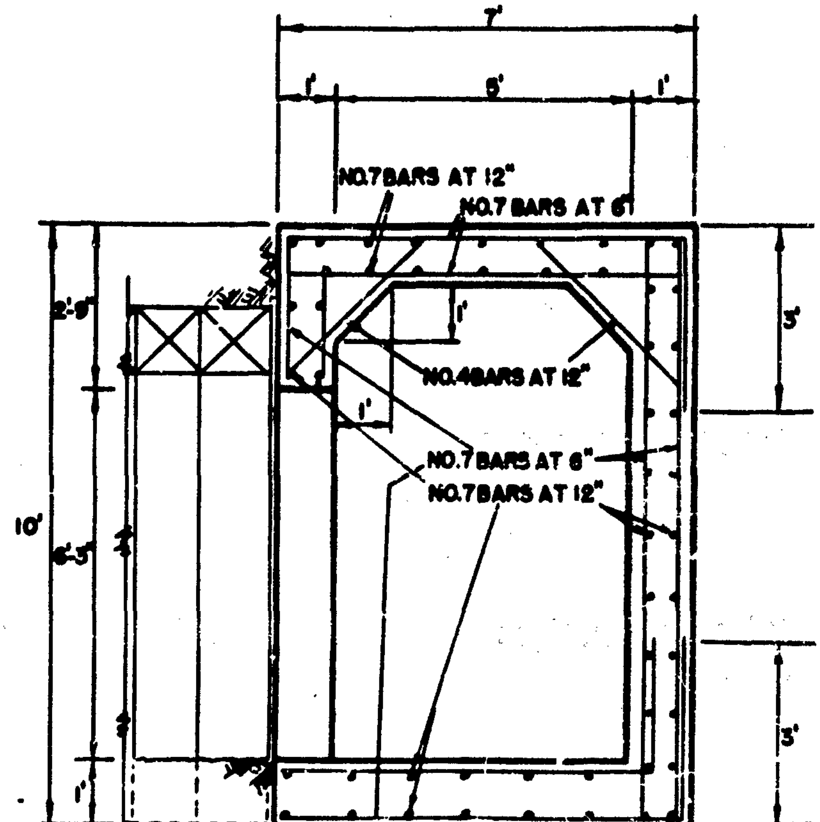


Fig. 44b. Exterior walk-through door foundation: Section B-B.

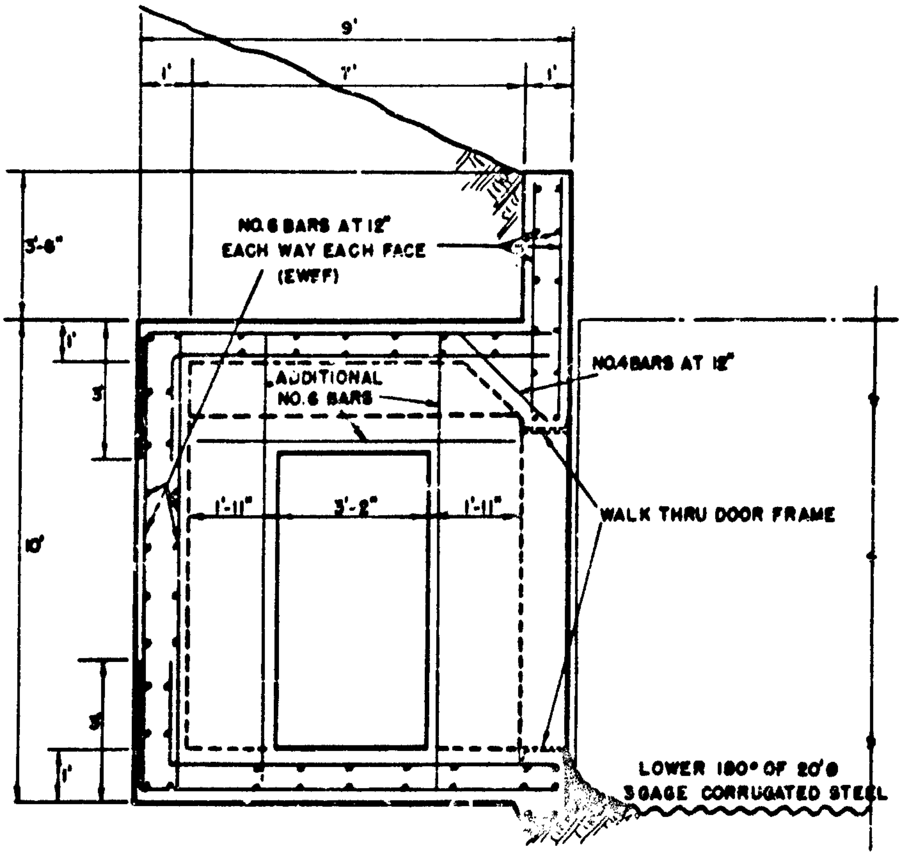


Fig. 44c. Exterior walk-through door foundation; Section C-C.

e. Reinforced Concrete Foundation for Massive Door. The drawbridge-type door (Figs. 38 and 39) which was tested under nuclear blast employed a combination entrance-frame structure. This structure, illustrated in Fig. 45, provides adequate strength and is long enough to develop fully buried conditions for the associated units. Even though a massive construction is required, the resulting entrance frame has a proved blast resistance capability.

14. Floors. The design of floors for the basic structures or its components, such as alcoves or entrance configurations, is considered separately as a result of nuclear test experience with varying types of floors. Designing for nuclear blast permits settlement and slight deformation of the structure. Thus, heave and differential movement are to be expected in the floor area. The possible

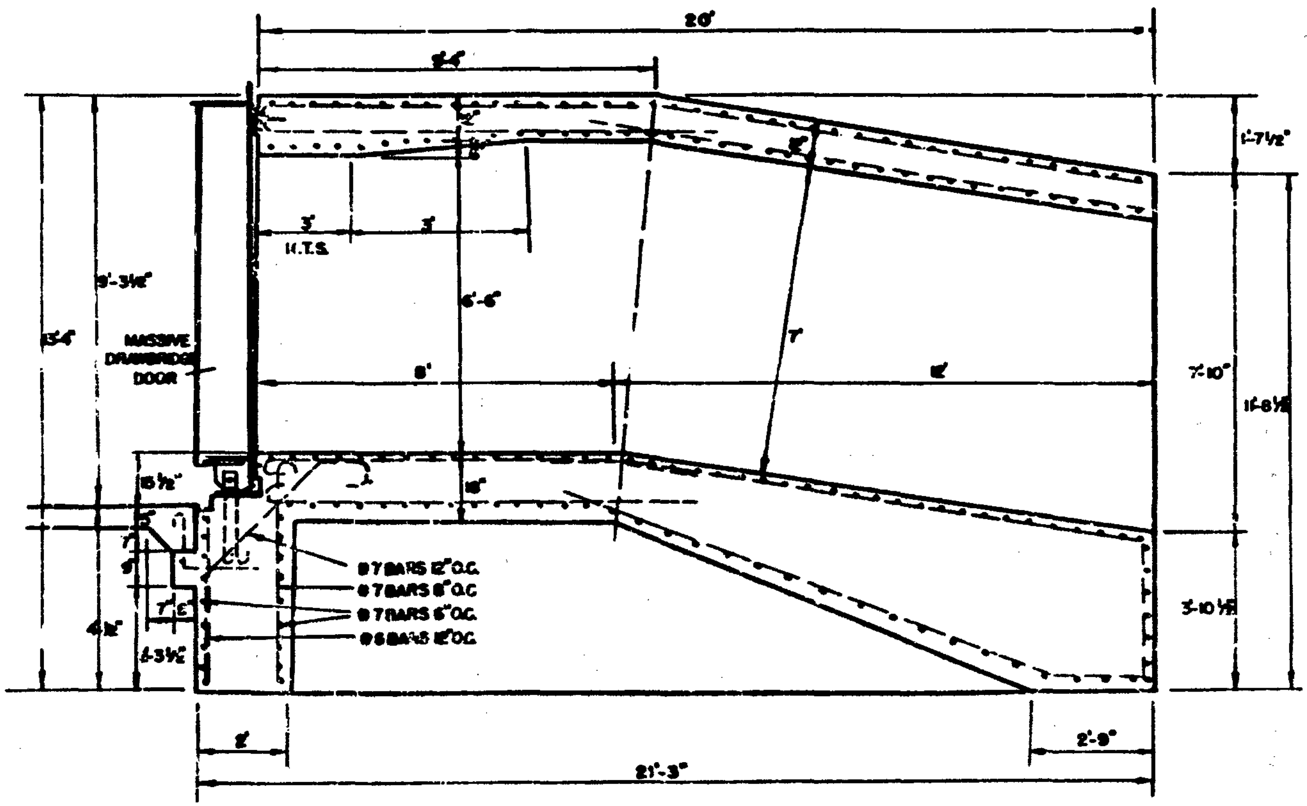


Fig. 4.a. Concrete massive drawbridge door foundation; vertical longitudinal section.

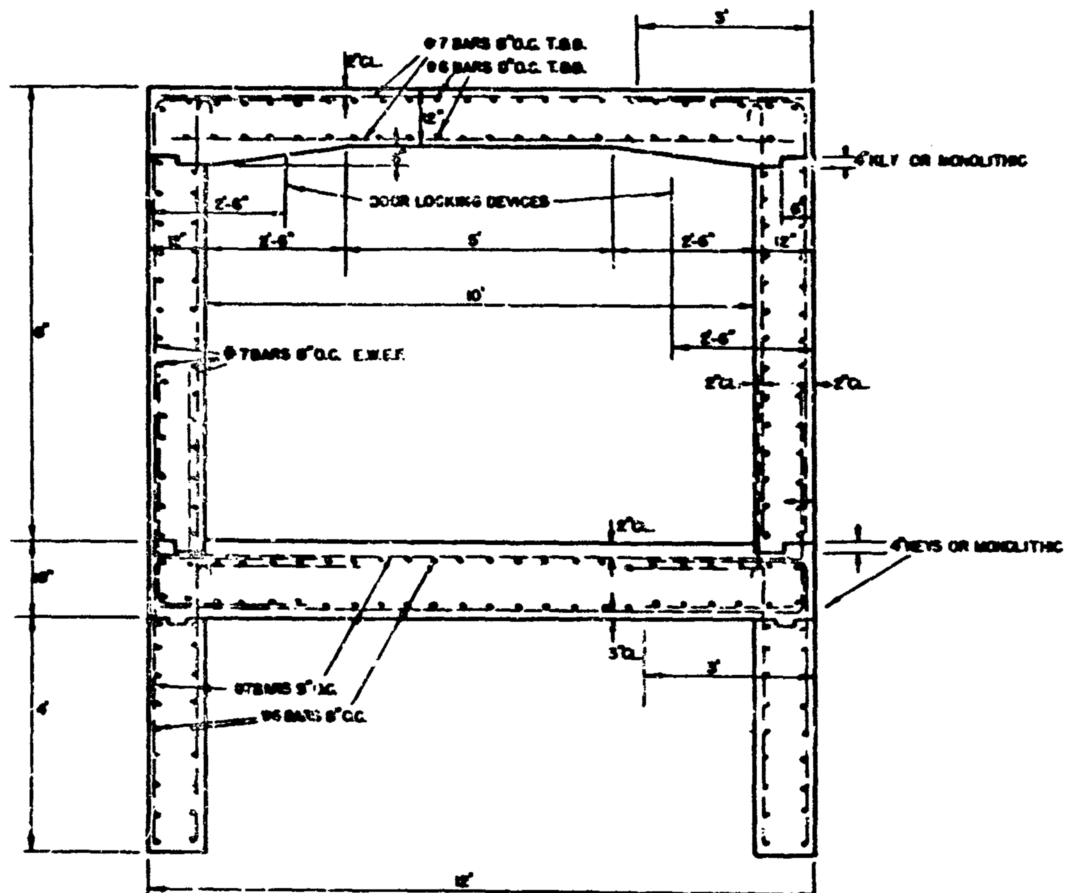


Fig. 45b. Concrete massive drawbridge door foundation; vertical transverse section.

uses of protective shelters may require rigid or high bearing strength floors. The types of floors are presented in order of desirability. The simplest type that will satisfy the requirements of the structure should be selected.

a. Sand or Earth. Well-graded and compacted earth forms a floor which is least likely to be affected by overpressure or blast phenomena. A sand or gravel floor, possibly with a stabilizing agent, would also be in this category but might have some undesirable features. An earth floor should be of the same quality of material as that required for backfill. Gravel or sand should not be employed in entrance configurations or near blast closures because granular material might be transported by overpressure leaking past the closure. Gravel might clog the seal and cause malfunctioning of the closure device. Lightweight rail equipment may be used with an earth floor to provide facilities for hauling heavy loads and yet retain the advantages of earth flooring. Sandbags may be used when a poor soil such as a clay, silt, or organic bearing material would otherwise be exposed.

b. Sectional Wood Flooring. The need to support equipment or the requirements of structure use and occupancy may necessitate a solid floor. Sectional wood flooring is the best type suited to resist the heaving or settlement of nuclear blast effects. This flooring, similar to that found in military squad tents, uses a wood sheathing wearing surface held by a 2-by-4 frame of dimensions suited to the floor plan. The largest section dimension should be no greater than 8 feet to facilitate handling and movement. The flooring thickness and design of the supporting cross members are determined by the use of the structure. The flexibility afforded by movable sections which provide room for inward displacement of the structure sides, furnishes the required resistance to damage by nuclear blast overpressures. Variations of this type of flooring would be pallets or flooring sections placed only on those portions of the underlying earth floor where specifically required (that is, covering a subfloor storage bin or providing a pallet for equipment mounting).

c. Pierced Steel Plank. Pierced steel or aluminum plank may be used as a flexible, heavy-duty wearing surface. To provide covering for an entire floor surface, the plank should be laid parallel to the major axis of the structure; earth heave or settlement caused by blast loadings is generally parallel to the footings. Pierced steel planking for wheeled truck lanes can be used in storage structures. Pallets or sectional flooring may be laid in the actual area of storage.

d. Concrete. A poured-in-place concrete floor provides a clean, excellent wearing surface which can be designed to withstand

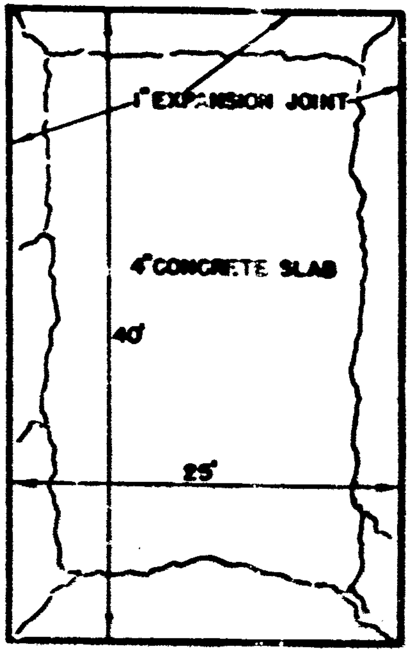


Fig. 46. Cracking pattern typical of a tested concrete floor.

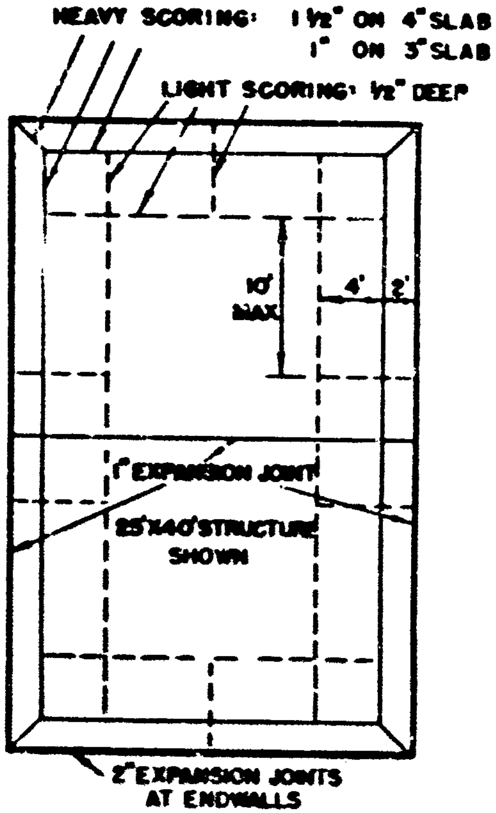


Fig. 47. Recommended concrete floor scoring and expansion joint patterns.

heavy loads and the adverse effects of nuclear blast overpressures. The concrete floor and its subgrade should be designed for depth and reinforcement on the basis of intended structure use. Unreinforced concrete floor slabs (f'_c = 4,000 psi) poured on compacted earth subgrade have been tested in side-on overpressure regions up to 100 psi in flexible metal arch structures. Under such nuclear tests, cracks were developed in the concrete (Fig. 46). Cracking under footing settlement and floor heave could be avoided by scoring and use of expansion joints (Fig. 47). Eight hundred square feet is considered a maximum for a single slab, scored as illustrated. Slabs of this size are likely to be impractical for small structures or restricted working spaces in underground construction.

IV. UTILITY COMPONENTS

15. General. This section presents the requirements, the bases for selection, and the specific designs, prototypes, and engineering data for utility components for protective structures. Emphasis on selection of designs and specific items of equipment has been based on proved performance, where available, from nuclear weapons effects tests. A minimum of detail has been presented for those facilities or items of equipment which employ conventional construction practices or are military stock equipment, more fully described in the referenced technical manuals. Selection of utilities as well as entrance configurations is dependent on the structure use. Table V presents recommended selections of utilities based on utilization. Selection of utilities for the various structure uses has been based on simplicity and on proved systems or equipment. For extended or preshot utilization, an economy of operation is desired which precludes the continuous use of emergency equipment. These principles have been followed throughout the presentation.

16. Electric Power and Lighting.

a. Battery Power. Battery-operated lights are required for every structure for use either in an emergency or as the sole lighting means for emergency shelters or storage structures. In addition, battery power may be required for communication equipment. Because of the fumes that may be given off by discharged wet cells, dry cell or sealed batteries should be the only type used in underground structures.

b. Engine-Driven Generator. Gasoline-engine-driven portable generators of the standard Army series may provide power for long post-attack periods or for intermittent preshot use. The specifications required for generator selection and their incorporation in the structure design are given in the list on page 87. As

Table V. Selection of Utilities Based on Structure Utilization

Intended Structure Utilization	Entrance Configurations (par. 11) (air lock recommended for all personnel shelters)	Electric Power and Lighting (par. 16)	Air Treatment Equipment (par. 17)	Water Supply (par. 18)	Sanitary Utilities (par. 19)	Emergency Equipment (par. 20)*
1. Storage	Vertical shaft, if possible, or horizontal entry; and tube to horizontal passage.	Battery-powered lighting. Central power for nonemergency use, if available.	None	Minimum storage. Conventional water supply, if available.	None or arctic bag or bucket type, emergency, or conventional nonemergency.	Gastight seal for massive entrance.
2. Emergency short-duration personnel shelter	Vertical tube to horizontal passage, filled emergency exit.	Battery-powered lighting.	None; volume of structure selected from Tables VI, VII, and VIII.	Stored 5-gallon cans.	None, or arctic bag or bucket type with drainage to separate pit.	Emergency air treatment equipment.
3. Emergency long-duration personnel shelter	Vertical tube to horizontal passage, filled emergency unit.	Battery lights and generator, if required, for filter.	Electric- hand- or engine-driven filter.	Wellpoint. Stored 5-gallon cans.	Bucket-type latrine, drainage to pit, tank, or tilefield.	
4. Personnel sleeping quarters and shelter	Vertical tube to horizontal passage, filled emergency exit.	Battery-powered lighting. Central power for nonemergency use, if available. Generator.	Electric filter.	Wellpoint. Stored 5-gallon cans. Nonemergency conventional water supply, if available.	Conventional units and outfall, bucket type with separate drainage for emergency.	
5. Emergency long duration personnel working and living station	Vertical tube to horizontal passage, filled emergency exit.	Battery-powered lighting. Central power for nonemergency use, if available. Generator.	Electric filter.	Wellpoint. Stored 5-gallon cans.	Bucket-type latrine, drainage to pit, tank, or tilefield.	Decontamination equipment.
6. Continuous occupancy working station	Vertical tube to horizontal passage, filled emergency exit.	Battery-powered lighting. Central power for nonemergency use, if available. Generator.	Electric filter, fan ventilation, antibackdraft valves.	Wellpoint. Stored 5-gallon cans. Conventional water supply, if available.	Conventional units and outfall, bucket type with separate drainage for emergency.	Decontamination equipment.
7. Radiation decontamination station in conjunction with 3, 4, 5, or 6	Vertical tube to horizontal passage, with integral large decontamination air lock.	Same as for the structure with which designed, 3, 4, 5, or 6.		Wellpoint, tank storage. Shower system. Stored 5-gallon cans.	Drainage to large separate pit for shower and contaminated water. Other units as with 3, 4, 5, or 6.	Radiac instruments for full range of radiations. Seals for entrance closures. Disposal bins.

* Emergency equipment for all protective structures: Wrecking and entrenching equipment; emergency rations; and protective masks for personnel; radiation detection equipment for all personnel shelters; intershelter communications equipment or radio with antenna. Protective clothing should be stored in any structure from which monitors will make aboveground surveys.

Specifications for Military Standards Generators

General: Temperature limits - -65° F to 125° F.
Brushes sealed or brushless, no ozone hazard.
28-volt direct, 60-cycle, and 400-cycle current available as separate models of the 0.5- to 10-kw series.
0.5- to 10-kw, 60-cycle series can be wired to give 120 or 240 volts single phase or 120/208 volts in a 3-phase Δ connection.
15 and 30 kw can be wired as 120/208 volts Δ 3 phase or as 240/416 volts Y 3 phase.

Generator output:	0.5 kw	1.5 kw	3 kw	5 kw	5 kw	10 kw	15 kw	30 kw
Cooling	Air	Air	Air	Air	Liquid	Liquid	Liquid	Liquid
Length (in.)	24	24	36	45	57	62	85	105
Width (in.)	19	19	25	29	26	23	32	36
Height (in.)	21	21	28	34	36*	37*	57	66
Dry weight (lb)	102	105	300	500	850	1300	2500	3500
Type mounting	----Tubular frame------			Skid	Skid	Skid	Skid	Skid
Fuel	Gasoline	Gasoline	Gasoline	Gasoline	Gasoline	Diesel	Diesel	Diesel
Fuel consumption:								
Lb/hr	1.5	3	5.5	7	7	14	18	36
Gal/hr	0.25	0.50	0.90	1.15	1.15	2.3	2.4	4.8
Lubrication oil requirements:								
Lb/hr	0.01	0.015	0.03	0.05	0.05	0.10	0.15	0.30
Intake air requirement: cfm	3	7	18	46	46	52	128	218
Engine heat discharged through cooling system:								
Btu/min.	125	250	500	835	835	1700	2550	5080

* Plus muffler

mufflers are not employed at the motor location with underground installation, the dimensions of the units shown may be used as the basis for design.

A gasoline-engine-driven generator and fuel must be placed in a room or alcove separated from the personnel shelter. The generator and gasoline supply may be located in a fireproof, gastight room within or below the floor of the basic structure or in a separate unit, connected to the main structure for access, and isolated by a gastight seal. Handling, storage, and replacement problems dictate that fuel should be stored in standard 5-gallon cans isolated from the walls of the storage bin or structure by an air space or sandbags.

The generator engine must be adapted to underground installation. A surface exhaust outlet and ventilator may be required to collect the cooling air expelled through the generator radiator. Generator air requirements must be included in design to ensure a small positive pressure differential within the structure at all times. The approximate air requirements of the generators are listed with the specifications. The means by which operating requirements may be satisfied are illustrated in Figs. 48 and 49. Selection of the various means of installation depends on structure utilization, hours of continuous operation, volume of the structure, number of personnel occupying the structure, and ventilation facilities. The specifications referring to the air requirements and standards for personnel should be noted in generator installation design to avoid overheating of the air by engine or generator cooling.

c. Central Power Source. A protected generator should be considered for continuous use with an installation consisting of several separate structures. Power cables protected by burial and placed to avoid shear at entry to a structure would permit economy of constructive effort, material, and fuel. The cables would supply electric power for continuous use. This means of providing electric power is most suitable for installations of two or more structures in proximity. In the actual installation, the generator or generators should be placed in a separate structure which should be connected by a horizontal entrance section, with a suitable gastight, blast resistant, closure, to an occupied area. Such an installation would permit supervised generator operation while the operators avoided the fumes. possible ozone concentration, and noise conditions in the power room. The installation of the generators could be similar to that shown in Fig. 48, although on a larger scale. For installations which employ one large-output generator, a second smaller generator should be considered to supply power for low-demand periods during which the principal generator is being serviced or fueled. A centrally protected generator installation may

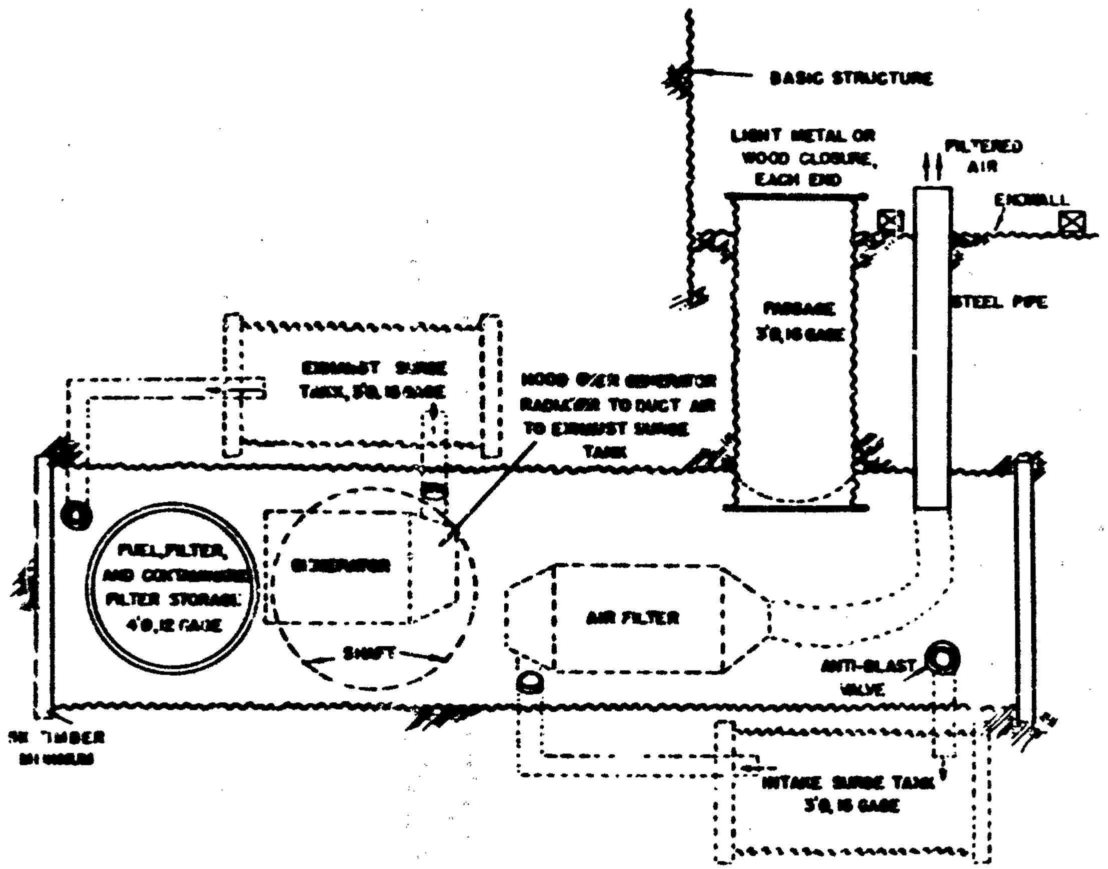


Fig. 13a. Independent generator, air-filter installation; horizontal section at midheight.

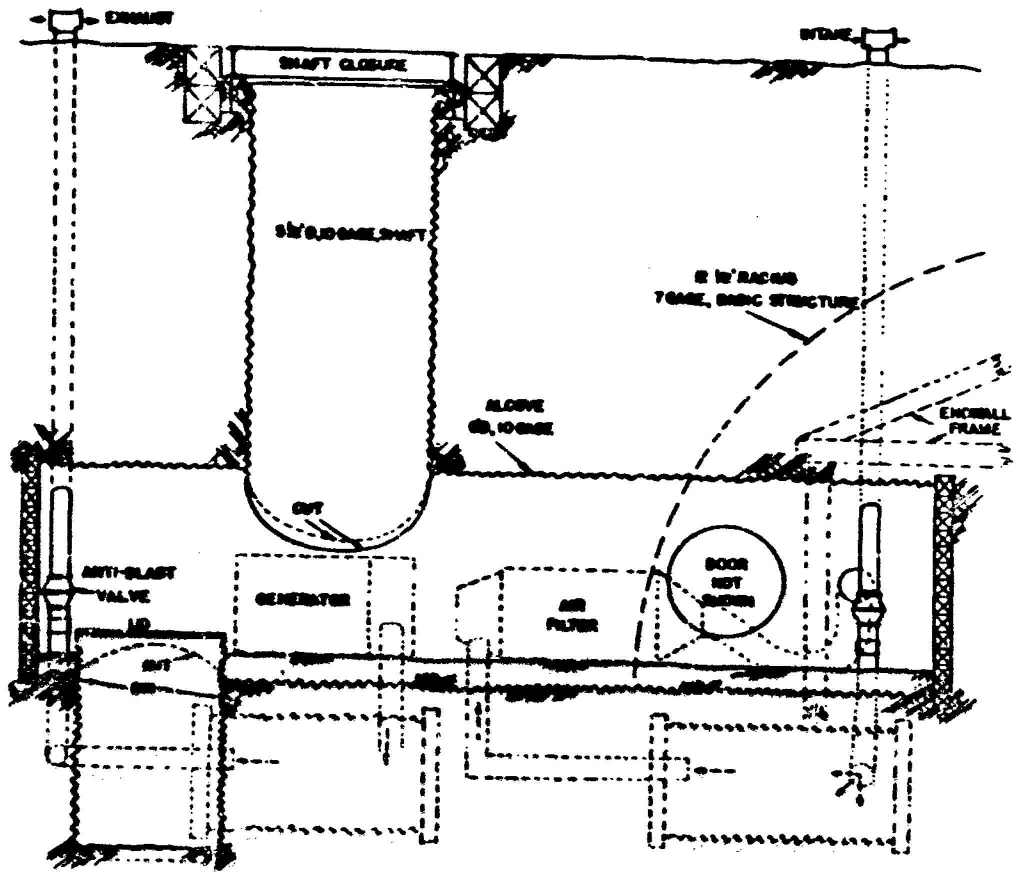


Fig. 48b. Independent generator, air-filter installation; vertical longitudinal section.

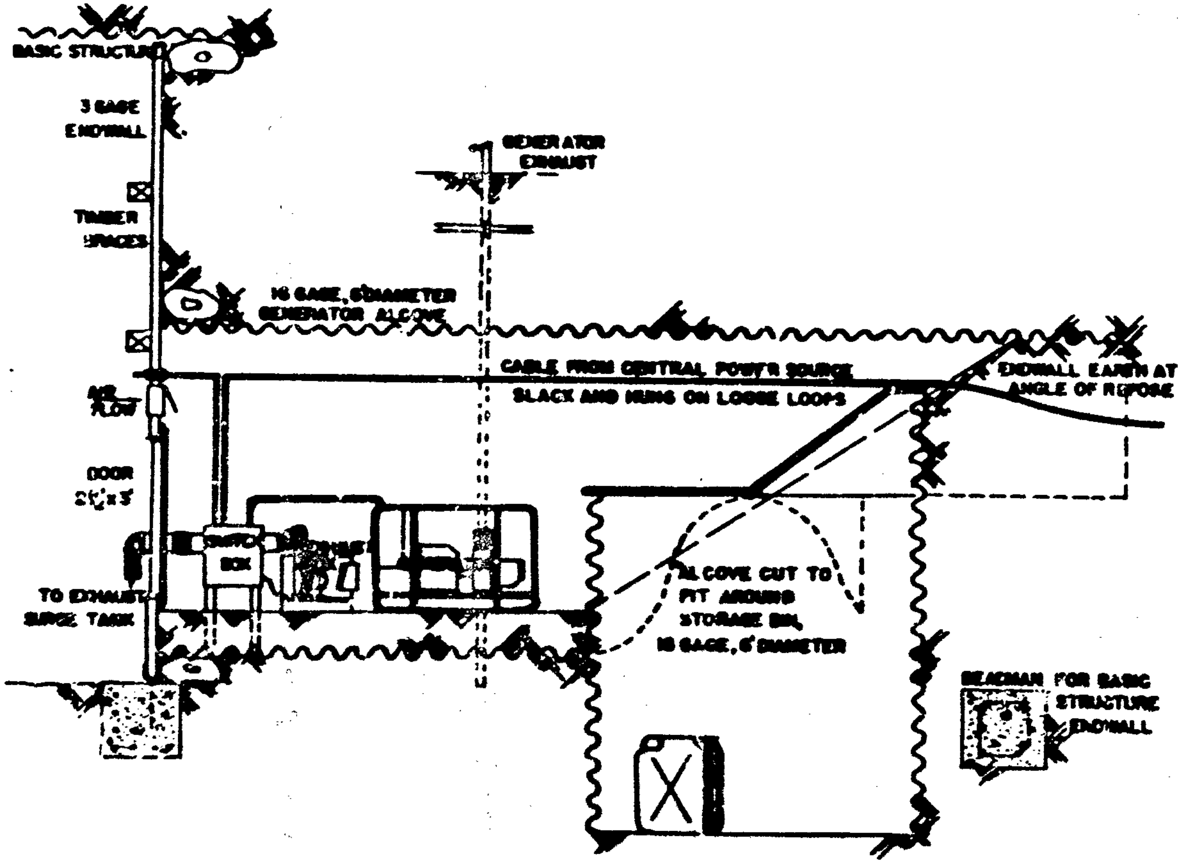


Fig. 49. Generator and storage alcove.

use conventional public utility power for economy, when available. The switchgear can be situated within the generator structure. To avoid continuous operation of emergency equipment, conventional power, if available, should be used before the blast.

17. Air Treatment.

a. Rudimentary. Structures for short-duration occupancy or for storage use may require no air treatment. The bases for design of structures having no treatment are given in Tables VI, VII, and VIII. An allowable sealed-in period may be computed using the following formula:

$$\text{Safe Allowable Period} = \frac{CO_2 \text{ Concen. Allowable} \times \text{Volume of Shelter } (Ft^3)}{\text{No. Personnel} \times CO_2 \text{ per person per hour } (Ft^3/hr)}$$

The safe maximum CO_2 concentration may be taken as 0.05 (5 percent).

Table VI. Minimum Ventilation and Space Requirements for Protective Structures

Period of Occupancy	Ventilation Rate per Person (cfm)	Total Surface Area per Person (ft^2)	Floor Area per Person (ft^2)	Volume per Person (ft^3)
Personnel at rest:				
	Oxygen consumption approximately 0.008 cfm.			
	Approximately 400 Btu expended per hour			
3 hr	None	30	6	50
12 hr	None	50	6	75
Continuous	2 cfm	25	6	50
Personnel at moderate activity (normal operations within a protective shelter):				
	Oxygen consumption approximately 0.028 cfm			
	Approximately 1,000 Btu expended per hour			
3 hr	None	75	6	120
12 hr	None	100	6	350
3 hr	3 cfm	25	6	50
12 hr	5 cfm	25	6	30
Continuous	5 cfm	30	6	60
Personnel at vigorous activity (unlikely in protective shelter):				
	Oxygen consumption approximately 0.056 cfm			
	Approximately 4,000 Btu expended per hour			
Continuous	10 cfm	30	6	60

Table VII. Effects of Temperature and Humidity

Temperature (°F)	Physical Effect on Occupants	Relative Humidity (%) for Borderline Comfort	Humidity (%) at Which Heat Prostration May Occur
50	Physical stiffness of extremities begins	85	-
60	65° optimum condition	80	-
70	75° physical fatigue begins	70	-
80)	85° mental activities slow	60	92
90)	down, response slows, and	45	90
100)	errors begin	40	90
120	Tolerable for about 1 hr, far above physical or mental activity range	-	-
160	Tolerable for ½ hr	-	-

Table VIII. Effects of CO_2 Concentrations

CO_2 Concentration in Air by Volume (%)	Effect
0.5	Desirable maximum.
1-2	Not noticeable, although it may reduce efficiency.
3	Slight effort needed to breathe.
5-10	Heavy breathing and rapid tiring.
10	Fatal, if present for any length of time.

Note: For computation in the formula for safe allowable period, use oxygen consumption for the CO_2 formation per person.

Unventilated emergency personnel shelters should be designed so that the blast closure is open at all times prior to use. The draft effect of the exposed entrance or, if necessary, intermittent forced ventilation, should be sufficient to keep the air of the structure fresh. If desired, emergency equipment such as oxygen tanks and masks, oxygen regenerating mask assemblies, and standard particulate filter and gas masks can be used. The standard gas mask should be worn when the blast closure is opened to allow air change after an attack. There is a small contamination hazard from such an action, and radiation monitors should be used. The individual gas masks provide good protection against the inhalation of airborne radioactive material. The absence of mechanical air filtration equipment may require the storage of radiac instruments and self-reading dosimeters, the provision of intershelter communications, and the training of all potential shelter occupants in various safety procedures.

b. Motor- or Engine-Driven Filter. Filtered air may be provided in a personnel shelter by means of the standard Chemical Corps filter units. These are gas and particulate filters in a family of sizes powered by an electric motor or as an alternative, by a gasoline engine as for the M-6, 300-cfm filter unit. The units are described in detail in the appropriate technical manuals. It is preferred to run the filters with an electric motor supplied by a remote blast-protected power source, thereby avoiding the need to satisfy exhaust, intake, and cooling requirements for separate gasoline engines. The specifications of the standard units are given in the list on page 95. An important consideration in the use of any filter unit is the heat output of the electric motor. Heat removal may necessitate a greater airflow than all other air requirements of the shelter combined. Air-filter units should be placed, whenever possible (essential for all but the smallest filters), in an alcove from which the air is exhausted direct to ground surface, thereby avoiding unduly large-capacity requirements.

The intake of the filter units must be protected by antiblast closures and surge tanks. In addition, the exhaust from the shelter should employ antibackdraft valves to protect the structure from contamination. These accessories are described in TM 3-4240-203 and, except for the surge tank, are standard items of Chemical Corps supply. The M-1 antiblast closure (a valve), illustrated in Fig. 50, has a maximum intake airflow of 300 cubic feet per minute. A higher airflow requires additional closures. Installation of the antiblast valve should be within an accessible area, to permit inspection and repair; however, the surge tank may be separate from the structure. A minimum surge tank capacity of 25 cubic feet is required for each M-1 antiblast closure. The surge tank may be constructed of culvert sections and placed below the floor of the structure. Inlets or exhausts to the surge tank for

Specifications of Standard Filter Units

1. Specifications of standard electric-motor-driven filter units designed to remove toxic gases, dust, and aerosols (solid and liquid particles) from incoming air in continuous operation:

Filter Unit:	ABC-M6	M-9	M-10	M-11	M-12
Technical Manual (TM)	3-420	3-4240-208-12	3-4240-209-12	3-4240-210-12	3-4240-211-12
Horsepower	1	1	2 (minimum)	5	7.5
Voltage	115/230	208/220/440	200/220/440	208/220/440	208/220/440
Phase (all 60-cycle)	1	3	3	3	3
Approximate kw	1¼	1¼	2½	6	10
Filter:	2-M9 partic. 2-M10 gas	M-14	M-15 (skid mtd.)	M-16 (skid mtd.)	M-17 (skid mtd.)
Capacity (cfm)	300	600	1,200	2,500	5,000
Dimensions (in.)	(Filter assembly is largest single component of unit.)				
Length	34	34½	62	62	62
Width	24	25½	25½	25½	49½
Height	22	25½	25½	25½	49½
Weight (lb)		310	550	1,090	2,240
Overall Dimensions (in.)	When assembled and ready for operation.				
Length	34	116	158	171	195
Width	24	30½	42	55	53
Height	39	34	39	39	64
Net Weight (lb)	400	800	1,200	1,700	2,800

2. Characteristics of ABC-M6 filter unit with gasoline-engine drive: Air-cooled, 4-cycle, manual starting, magneto ignition, 1½ hp, and fuel consumption approximately ½ pint/hr.

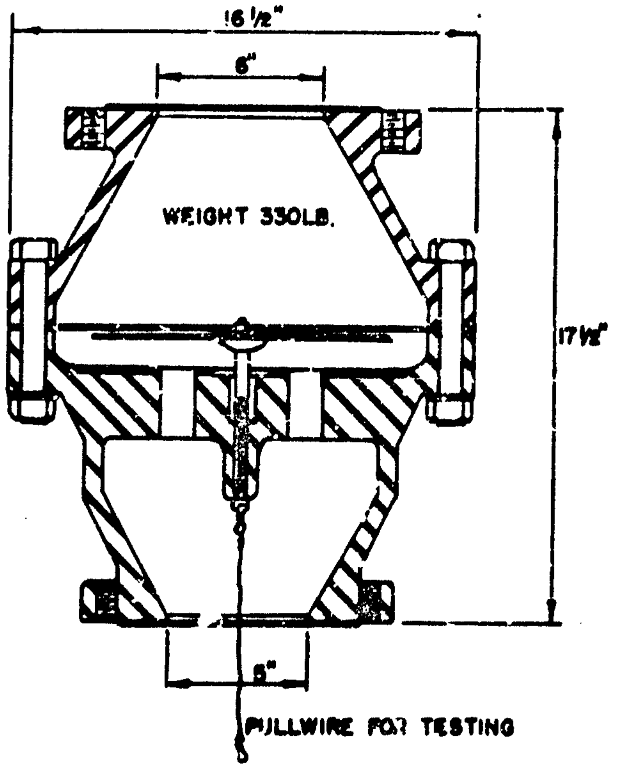


Fig. 50. M-1 antiblast closure.

the filter, exhausts, heaters or motor can be made through holes in the culvert section or through the timber end wall. Details of a suitable installation are shown in Fig. 51. Figure 48 illustrates valve and surge tank installations in a separate generator-filter structure. Antibackdraft valves should be used between partitioned areas of a shelter and on vents leading to the exhaust surge tank. A typical shelter floor plan employing these items is shown in Fig. 52. Details of the generator and latrine alcove installations are included in Figs. 49 and 53.

Use of a gas-particulate filter allows personnel to avoid the inhalation of radioactive particles in the form of weapon products dust from induced radiation areas or from the fallout contamination of a surface burst. However, this radioactive material trapped by the filter is a possible source of high-intensity radiation. The location of the filter unit should afford shielding from the occupied area of the structure. Gamma radiation is the

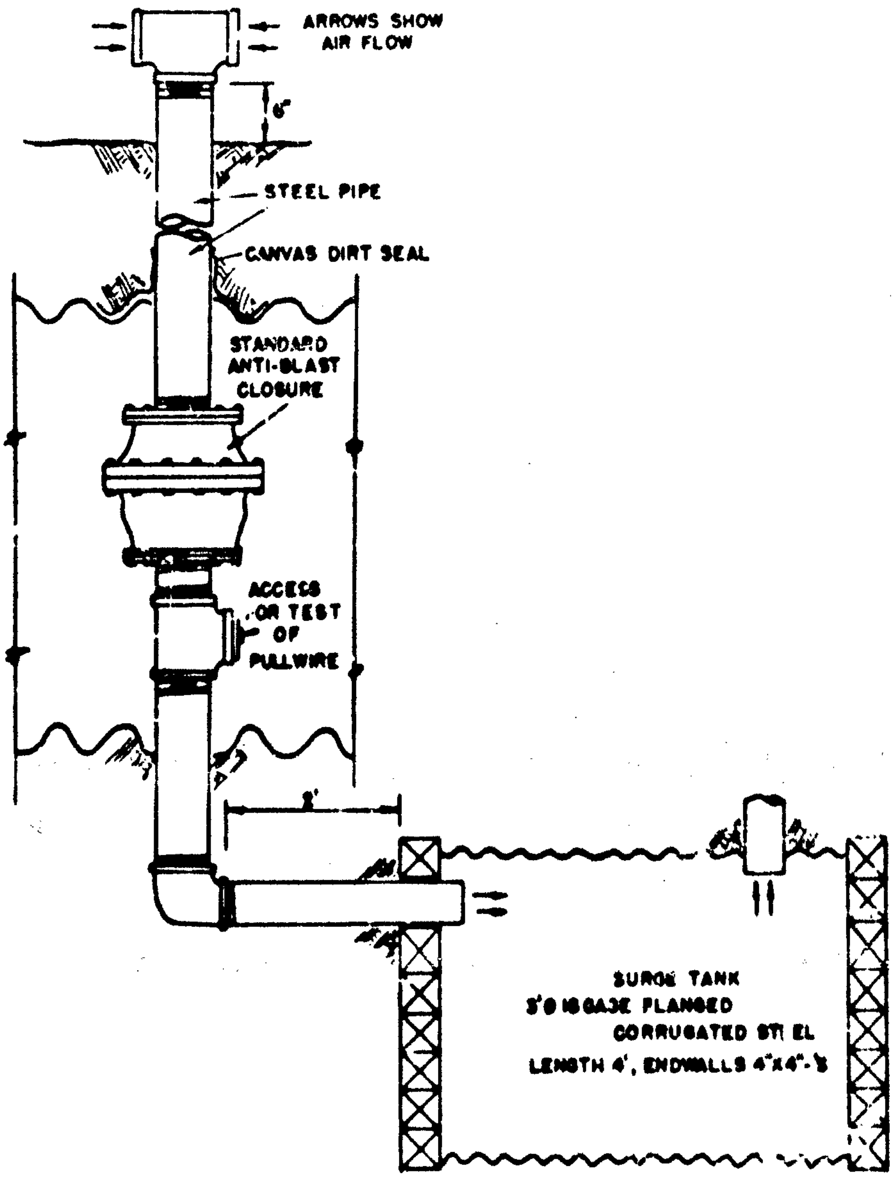


Fig. 51. Antiblast closure and surge tanks details. Twenty-five cubic feet of surge tank volume are requir.d for each M-1 antiblast closure (capacity 300 cfm) employed.

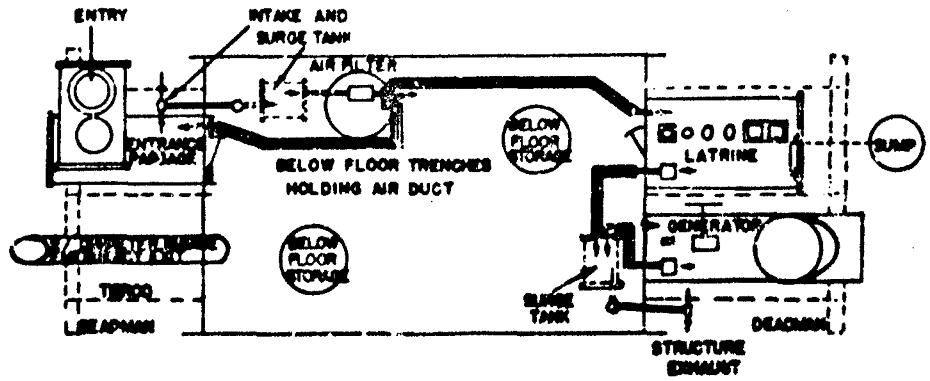


Fig. 52. Typical shelter floor plan; air flow illustrated.

principal type emitted by such radioactive material. Furthermore, it is the type that requires the greatest mass of shielding for reduction in its intensity. Adequate shielding is easily obtained by means of a large earth separation between the radioactive material and the occupied area. Replacement filters should be stored within the structure. A means of sealing contaminated filters (plastic bags) and a safe place for their burial (for example, a pit in the earth floor of an alcove) should be provided. Here, mechanical filter and air change equipment increase the safety requirements for radiac instruments, self-reading dosimeters, and training of the possible shelter occupants.

18. Water Supply.

a. Storage. The most convenient, blast resistant means of water storage is the standard 5-gallon can. Water treatment chemicals should be kept on hand for preserving long-stored water, but a rigid system of regular replacement of the stored water should be used. The cans should be stored upright, and can be placed within the structure itself or in separate areas. The amount of water to be stored depends upon the structure use and the duration of occupancy that is anticipated. A minimum of 2 quarts per occupant at maximum occupancy should be stored in any protective structure. One gallon per person per day should be used as a minimum storage requirement for long duration occupancy. Storage tanks or drums should be within or below the structure to lessen shock damage. The tanks should be of metal or a more flexible material and should be located so that drainage after rupture will be into the subgrade and not on to the structure floor. Rubberized tanks below the floor level could be employed for large-capacity storage. Means of emptying and refilling the tank should be provided. A previously unused standard 10,000-gallon collapsible neoprene POL tank (dimensions 42 by 11 by 4 feet) may be placed in a pit below the structure floor. Because of the composition of the tank material, the water should be changed weekly and be used only under emergency conditions. A means of post storage treatment would be desirable. A collapsible tank as described could provide a protected central water supply for protective structures.

b. Well Point. If the ground water is potable and the water table is relatively close to the floor level, use of a well point should be considered. A well point would be the best method to augment the water-storage capacity of the structure. The installation would require a remote, blast-protected sewage outfall or a carefully designed tank or field sewage disposal system. Arctic-type plastic bags for sewage waste disposal would require less storage space than for water storage and may be an effective means of allowing employment of well point water. Nevertheless, chemical treatment (for example, Halazone) is necessary if pumped water is to be stored.

c. Water Distribution System. A water distribution system may be used to supply washing and sanitary needs, depending upon the type of structure. Continuous use structures which are occupied for sleeping or working may have conventional water supply systems, if available. Caution should be exercised in installation of the system to insure that pipe breakage from differential structure-earth settlement does not cause a line to break or drain into a structure. Steel or copper pipe is adequate for this purpose. Pipes should neither be cast in concrete, nor should they be placed directly below foundations. The best pipe entrance is through or under a horizontal passage section into the structure. An end wall where the principal response to blast is horizontal movement into the structure, is an alternate point of entry for utility lines, either through oversize ports or well below the foundation.

When adjacent personnel shelters exist, consideration may be given to a protected water supply system with a pumping and treatment plant in one central structure. Deeply placed steel pipe would be suitable for the distribution lines. The water source may be a well point or protected lines from a stream or reservoir. The treatment and pumping equipment could be installed in a manner similar to the separate generator air-filter installation (Fig. 48). As with the electric and air supply utilities, continuous use of emergency equipment should be discouraged. The items may be of limited cumulative capacity, as in water storage or filtration equipment, or may not be intended for continuous operation without maintenance or repair. This situation would apply to sewage storage facilities or gasoline-engine-driven generators and filters. As with all the utilities, potential occupants should be familiar with the functioning and capabilities of the equipment and with procedures which insure group safety.

19. Sanitary Utilities.

a. Minimal. No sanitary facilities need be provided for storage or short-duration personnel structures. As an alternative, buckets or arctic-type plastic bags may be installed or made available. The existence of a blast-protected space, as with a storage-only structure, is sufficient to assume personnel occupancy during or after an attack, and sanitary as well as other emergency utilities may be provided on this basis.

b. Bucket Type. Any structure may be furnished with bucket-type latrines, troughs, and washstands, as detailed in other technical manuals, such as TM 5-302, Construction in the Theatre of Operations. Direct or transferred drainage to a separate pit should be provided. Where feasible, the latrine section should be isolated from the basic structure by partitions or by location in a separate alcove partitioned from the structure (Fig. 53). Unless the drainage is to a tank with an outfall or a blast resistant (deeply placed) tile field, an alternative to the pit or tank means of waste disposal should be provided for nonemergency use prior to a nuclear attack. An outfall to a conventional sewer system or tile field should be employed preshot to avoid loading the limited capacity of the underground sump.

c. Conventional Plumbing. Conventional sanitary utilities, emplaced as detailed in TM 5-302, may be employed for occupied structures having a piped water supply. Except where a blast resistant central water supply exists, these utilities should be augmented by bucket and sump-type facilities. Outfall should be of cast iron, concrete, or corrugated steel pipe and should be to a lagoon, a conventional sewer system, or a tank-type facility. An underwater outlet to a lagoon or stream would be the most blast resistant, although conventional valves and a surge tank may be used to prevent back flow from blast overpressure. Care must be taken in design, construction, and provision for maintenance, to insure blast protection for the structure and dependable operation of the system. Almost all plumbing fixtures, valves, and piping designed for domestic usage have sufficient strength to withstand the subsoil earth pressures of 50-psi side-on overpressure region. Brittle pipes such as those fabricated from asbestos, concrete, or impregnated composition fiber would be unsuitable because of earth settlement or applied pressure.

20. Emergency Equipment. Depending on the type of structure, provisions should be made for enforced long-duration occupancy; damage to standard exits; radiation decontamination and monitoring;

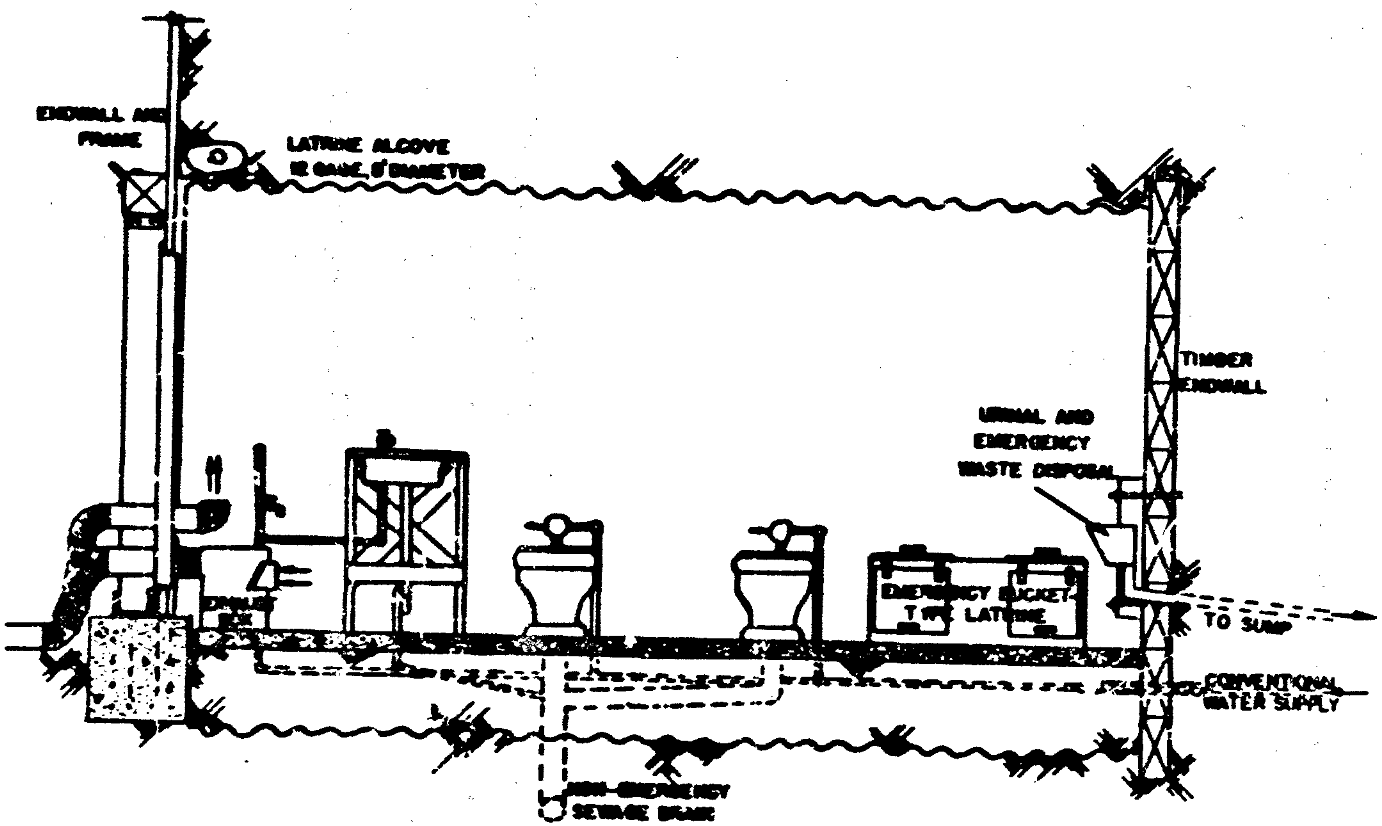


Fig. 53. Latrine alcove.

emergency structure-surface communications; and breakdown of the air supply system. The items noted in this section should be selected as required, dependent upon use, space, and structure vulnerability. Emergency equipment should be stored as close as possible to the center of the basic structure, preferably in an accessible, protected, subfloor storage bin. All occupants should be acquainted with the location and contents of the emergency equipment and its use.

a. Exit-Forcing Equipment. Excessive overpressures are likely to cause partial failure of some of the structure components. The designed blast closures are most vulnerable to partial failure, jamming, or blockage caused by external debris or transported soil. Exit-forcing equipment should be stored in every structure to permit occupants to dig their way to the surface. The compaction and selection of backfill required to satisfy structural requirements would tend to facilitate such action. Exit from a structure may be possible by the following methods: (1) unbolting the "hold downs" of a blast closure; (2) excavating through an angle-of-repose end wall; (3) removing the sand from a filled-type emergency exit; (4) unbolting corrugated steel plates and excavating; (5) unbolting one of the tie rods from a deadman to enlarge the separation between an end wall and the basic structure through which to tunnel to the surface; (6) excavating below the foundation and then up to the surface, or any other method which might apply to the particular structure configuration. Equipment that should be available for such operations are shovels, picks, pry bars, wrenches, hammers, and chisels. The list can be lengthened or shortened depending on the materials employed in construction and the number of occupants.

b. Food. Standard packaged rations should be stored in structures intended for long-duration occupancy. The amount and type of these rations is dependent upon the anticipated number of personnel and the utilities available. The standard "C" and "5 in 1" rations are suitable for this purpose and have moisture-resistant packaging. The volume of the standard rations is shown in Table IX:

Table IX. Emergency Rations Requirements

Type Ration	Rations/ Package	Weight/Package (lb)	Volume/Package (cu ft)
Small Detachment, 5 in 1	5	27	0.8
Individual "C", Combat	6	40	1.1
Food Packet, Individual, Assault	24	39	1.3
Food Packet, Survival	24	-	0.63

Note: All rations listed are precooked and may be eaten cold or heated. One ration is the requirement of one man for 1 day.

Storage space for the rations should be organized so that used boxes containing waste can be stored in areas previously occupied by the full containers. Cooking or other food service equipment is neither essential to protective shelters nor desirable. The heat and combustion products of cooking create additional air change requirements. Rations may be heated, if desired, by placing them near the generator engine or by immersing in drained engine radiator coolant.

c. Communications. Signal Corps equipment has been designed to withstand severe shocks or vibrations and may be mounted in normal locations within a protective shelter. Equipment should not be affixed to or placed adjacent to outside walls or structural partitions. Wires should enter the structure by protected means, similar to those which have been described for water supply pipes. Entranceways furnish excellent accessibility and a means of avoiding sharp structure-ground differential settlement. Cables can be attached loosely to the basic structure for convenience, but slack should be left in the lines to avoid parting in the event of partial deformation of the structure under excessive overpressures. A telephone within a blast resistant cannister close to the structure entrance at ground surface would be advisable to insure outside communications after a damaging attack. Instructions for signaling by striking the blast door may be posted outside of the structure. A filled steel pipe, containing wire with leads for attachment to a handset or other telephone equipment, could be run from the structure to the surface to facilitate post-attack communications. Standard signal equipment can withstand nuclear shocks experienced within protective shelters, as has been proved by weapons effects tests. A radio antenna, tested by exposure to high nuclear overpressure, is illustrated in Fig. 54.

An alarm system should be provided all protective structures by which alerts issued centrally are sounded within the structures. Bells or buzzers should be employed for such purposes. They should be connected by blast resistant lines placed as described for the other signal equipment. The central station for the alarm system should be in a blast resistant structure and it should be possible to test the alarm facilities at any time to insure their correct operation.

d. Emergency Air Treatment. Certain equipment is available which would increase the time period a personnel shelter may remain habitable without adequate air change. Examples are Chemical Corps oxygen regeneration mask assemblies; tanks of compressed oxygen or air with individual masks; and commercial equipment such as air purifiers and oxygen regenerators. Obstruction or other failure of the air-circulating equipment could be offset by use of the emergency equipment or by opening the blast closure, checking for

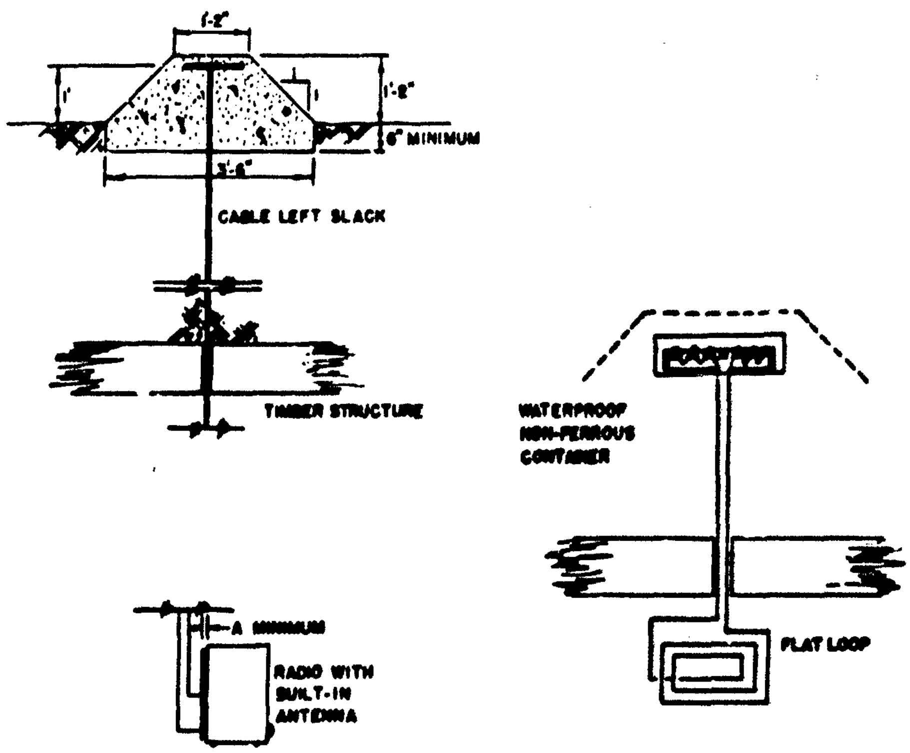


Fig. 54. Blast-tested antenna installation.

air-carried radiation. Should surface radiation be high and the air contaminated, the use of the standard protective mask and disposable clothing, such as coveralls, gloves, boots, and hoods, would permit the occupants to open the blast closure and circulate the air without leaving the structure or receiving a harmful radiation dosage.

As with all of the emergency and other operating equipment, procedures to be followed under foreseeable circumstances should be itemized and each occupant should be familiarized with the safety procedures and the equipment operation.

e. Radiological Defense Equipment. Equipment such as the tactical dosimeter Radiacmeter IM-93/UD and technical self-reading dosimeters should be available in all radiation decontamination stations, and their use is advisable within any personnel shelter. Disposable clothing, tape, and boots should be stored within any structure from which monitors will check surface radiation. Dose rate

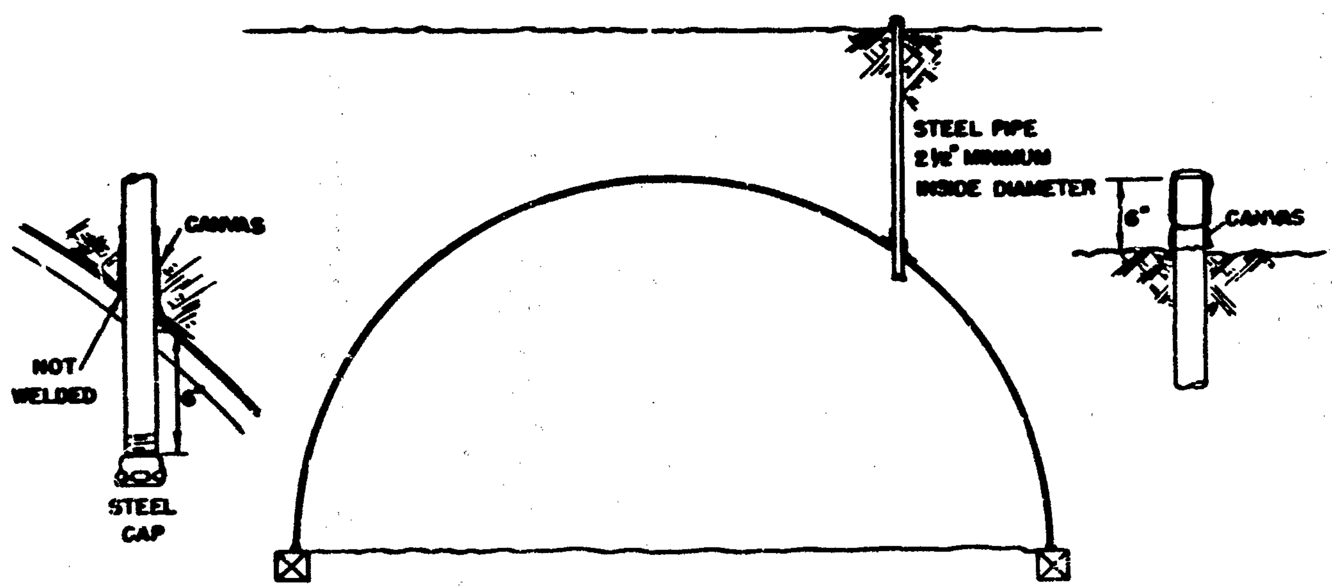


Fig. 55. Provision of means of monitoring exterior radiation.

radiacmeters are required to confirm the safety of filtered incoming air, and to check for leakage around blast closures. Means by which a gastight seal can be made about an entrance should be on hand within the structure and may be only a large plastic film which can be tacked or taped around the entrance-structure junction. A means of measuring radiation on the surface (Fig ,5) is suitable for use of an AN/VDR-1 monitor with an extensible handle section or a self-reading technical dosimeter mounted on a rod. Other equipment which can be employed for radiation safety discussed in TM 3-4240-203, Accessory Equipment for Protective Shelters, includes description of the antiblast closure, antibackdraft valves, an air-pressure regulator, and a contaminated clothing chute.

V. STANDARDIZED DESIGN PROCEDURE

21. General. The procedures by which the field engineer fulfills the requirements placed upon a protective structure design are itemized to ensure comprehensive coverage of structure design and utilities selection. The variety of choices available to the field engineer, the importance of continuity in the assembling of components to form a structure, and the selection of adequate utilities for the structure, however call for a system of design steps to provide a logical procedure which is developed in this section. This method is followed in the design of sample protective structures. The sample structures are not singular solutions to the requirements set forth because such factors as material, time, constructive effort, and utility availability necessitate widely varying design criteria.

22. Development of Procedure Sequence. The basic tools in the design of structures by proved components are set forth in Tables V and X. In a logical sequence, these tables are used as an aid in structure design. Certain factors, such as materials, manpower, equipment, time, and function of the structure should be considered before component selections are made from the appropriate tables. The steps of the procedure are presented in detail in the following subparagraphs:

a. Establish Minimum Structure Requirements. The directive for the design of a protective structure should be accompanied by certain specific information which the field engineer requires as basis for the design. This required information includes the following:

(1) Intended Structure Employment. A description of the use for which the structure is intended is the principal criteria of design. This description may be designation for storage, emergency personnel shelter or other classification, as appropriate.

Table X. Protective Structures and Structural Components

Structure Components Classification	Designs	References Par.	References Tables-Figures
Basic Structures (par. 9) (length immaterial)	1. Circular Corrugated Steel Cattle Pass	9a	11,12
		9a	I,13
	2. Corrugated Steel Arch	9b	11,14,15,16
	3. Circular Reinforced Concrete	9c	18,19
	4. Timber	9d	II,III,20,21, 22,23
End Walls (par. 10) (see Table IV)	1. Deadman-Supported End Wall	10a	24,25,26,28
	2. Structure- and Deadman-Supported End Wall	10b	25,27,28
	3. Earth at Angle of Repose	10c	49
Entrance Configuration (par. 11) (see Table V)	1. Vertical Tube to Horizontal Passage	11a	29,30
	2. Vertical Shaft to Horizontal Passage	11b	31,48
	3. Horizontal Entry from Surface	11c	44,45
	4. Entrance Through an Exposed End Wall	11d	38,39,45
	Filled Tube Emergency Exit	11e	32,33
Blast Resistant Closures and Frames (par. 12)	1. Designed Personnel Hatch	12a	30,34,35
	2. Closure for a Rectangular Shaft	12b	31,36
	3. Designed Walk-Through Door	12c	37,42,45
	4. Massive Drawbridge Door	12d	38,39,45
Door Frame-Supporting Foundation (par. 13)	1. Corrugated Steel Retaining Rings	13a	30,34,40
	2. Reinforced Concrete Bearing Pad	13b	35,41,42
	3. Concrete Rectangular Hatch Foundation	13c	43
	4. Walk-Through Door Foundation	13d	44
	5. Reinforced Concrete Frame Foundation for Massive Door	13e	38,39,45
Floors (par. 14)	1. Sand or Earth	14a	
	2. Sectional Wood Flooring	14b	
	3. Pierced Steel Plank	14c	
	4. Concrete	14d	46,47,53

Note: Components in each classification are listed in the order in which their use should be considered.
Selection of a component from each classification is independent of selections from the other classifications.

(2) Volume of Storage Requirements. A precise designation of the equipment to be stored within the structure or the volume required for bulk storage should be provided. This information may accompany the directives for the use of storage structures or may constitute the requirements for auxiliary storage, secondary to another principal structure utilization (that is, such as a need to store crew-served weapons and ammunition in a personnel shelter).

(3) Number of Occupants. This number includes the permanent party who might live or work in a structure continuously, the number of persons who might work or seek protection in a structure under emergency conditions, or the persons who may find shelter in a storage structure.

(4) Duration of Stay. Either the directive or the field engineer must set the duration which the structure occupants may be required to stay in place and, as in a continuous occupancy working station, remain without receiving supplies or leaving the shelter. This information is required to establish air change, fuel, food, and water storage requirements. A time for emergency occupancy of the structure may also be selected. The interval is set by factors such as the tactical mission of the personnel, the number of people to be sheltered, and the mobility and communications of the personnel if area evacuation is required. For example, personnel may be able to leave a shelter with a secure communications system and thus receive directions and routes for evacuation at an earlier time than they would had the time of exit from the shelter been determined on the basis of dose rate measured at the structure entrance. Forward tactical positions may be designed on the basis of two to four hours' emergency occupancy, as the personnel would be required to man battle positions or effect tactical maneuvers immediately after an attack. Structures located where the personnel would not be required for immediate post-shot activities (as in shelters provided for civilians or administrative personnel) may be designed to permit longer periods of stay.

(5) Special Entrance Considerations. Storage of material of large dimensions or requiring special handling may necessitate special entrance designs. If these specifications preclude the use of vertical shafts or require special hauling equipment, detailed descriptions of the stored material should be furnished with the other design criteria.

(6) Overpressure Region. Specification of a design side-on overpressure region need not be made except when it is desired to provide protection much greater or much less than that for 50 psi. The large amount of data available from tests

in the 50-psi region, the realization that absolute protection is a practical impossibility, and the need to design on the basis of pressure to achieve balanced design of structure components indicate the advisability of using 50-psi side-on overpressure for military tactical purposes.

(7) Special Equipment and Requirements of the Commander. Use of communications, plotting, or computing specialized equipment as may affect the generator, the floor area, the height, or other requirements should be included with the criteria. The commander should permit the field engineer to exercise latitude in selection of materials and designs. Special requirements for facilities should be set forth with the initial criteria, as underground construction discourages later alterations or additions.

(8) Special Criteria. The following items may or may not be included in the directive of design:

(a) Duration for which the structure will be required. This is a factor which may determine the utility of timber or the necessity of applying paint or preservatives.

(b) Time available for construction. This may prohibit the use of poured-in-place concrete or of materials not within the unit area.

(c) Specification of unit responsible for construction. The directive of design is incorporated in an operations order.

(d) Provision for protection against conventional weapons. Nuclear blast resistive structures do not provide inherent protection from conventional weapons other than small arms. Protection against destruction by bomb or shell penetration, high explosive cratering, or shattering effects must be considered separately. Such situations may be mitigated by addition of a burster course and would require considerably deeper burial of the structures. Deeper placement would not require additional strength because the increase in dead load would be more than offset by attentuation of blast loading with depth.

b. Ascertain Material Availability. The first step of the field engineer after receipt of the minimum structure requirements is to determine the materials available. The procedure may be simplified by a review of the minimum structure requirements and a search for the materials of construction in order of desirability of employment, as set forth in Table X. As an example, for a structure not requiring a massive drawbridge or walk-through exterior door, the field engineer should determine if corrugated steel arch material is available for the structure and need not extend his search to include the other structure materials. Timber for deadmen, footings, and end walls and steel stock for hatch fabrication are required in almost all structures. The pertinent information for the various types of materials of construction follows:

(1) Corrugated Steel. The availability of arch-type corrugated steel should be ascertained as to varying gages, radii, amounts, section characteristics (type of steel, pitch, and depth of corrugation if other than 2 inches by 6 inches, American commercial standard), and types, such as flanged or preassembled sectional plate. Data required for straight-type corrugated steel sheets are the gage, the pitch and depth, the sheet length, the steel type (if other than that of standard American commercial practice, f_y = 27,000 to 28,000 psi), and the amount available.

(2) Concrete Pipe. Should the type of structure or scarcity of corrugated steel indicate that concrete pipe may be employed advantageously in the construction, the data required would be the diameter, the wall thickness, the length of sections, the number of sections, and the specifications to which the pipe was made. If the internal construction of the pipe is in doubt, the D-load to produce a 0.01-inch crack and the D-load to produce the ultimate load should be ascertained by test. (Cf. Section III, par. 9c, "Circular Reinforced Concrete.")

(3) Concrete In-Place Construction. The information required to determine the suitability of concrete in-place construction is the availability of the cement, suitable aggregates, and reinforcing which may be of different sizes, lengths, and types (applicable to foreign construction where different deformation patterns may effect certain design criteria). In addition, material suitable for construction of forms, falsework, and scaffolding must be available.

(4) Timber. Timber may be required for every structure for use in passageways, shafts, shaft closures, end walls, footings, deadmen, or in the basic structure. The field engineer should obtain a list of sizes, lengths, amounts, types, grades, and conditions (green or air-dry) of timber. The detailed information may be used to determine the applicability of the approximate design method presented here or may show that the design assumptions must be modified because of a large departure from the average values used in the derivation. The availability of treated timber or preservative coating compound

should be determined for semipermanent structure design in moist or organic soil. In addition, suitable timber fastenings must be available.

(5) Structural Steel. It is not necessary to obtain information on the supply of structural steel unless specific structure requirements or the scarcity of other material necessitates this type of construction. An exception may be made in the use of structural steel for deadmen and foundations for semipermanent construction, and in the need for steel in closures, frame, and frame foundations. If the steel is available only in limited lengths and shapes, specific data on the sections and lengths are required prior to design. Otherwise, the design should be based on the section modulus and use of structural intermediate steel (ASTM A-7). Selection of sections which will match or fulfill these design requirements then can be made.

(6) Utilities. The means of supplying the utilities must be decided prior to structure design to provide the area, storage, access, and alcove requirements which must be incorporated.

c. Construction Time. Depending on the position of the field engineer and the requirements of the commander, the time available for construction can be a factor influencing the selection of materials and the structure design. This factor is closely related to the equipment available because, with sufficient time, some work may be feasible without special tools. An example would be the placement of concrete pipe or structural steel without adequate power lifting equipment. Similarly, the lack of skilled manpower may prohibit certain types of in-place concrete or steel construction when time is critical.

d. Site Characteristics. Site characteristics may be considered in design by the field engineer. If a specific site has been designated for the structure, the backfill, a requirement for borrow backfill, the water table elevation, and the runoff characteristics of the surrounding area should be determined. In other circumstances, the structure may be designed and then an appropriate site may be selected by the field engineer.

e. Design of Structure. With data obtained from the steps just given, the final design may be made. A chronological sequence with appropriate explanations leading to the completed design is presented in the following:

(1) Establish the specific utilities, the emergency equipment, and the entrance configuration to be employed.

Reference should be made to Table V, "Selection of Utilities Based on Structure Utilization," and the structure requirements. Means of electric power supply should be selected on the basis of equipment and lighting needs and a preliminary selection of air treatment equipment.

Final selection of the air treatment facility is based on air change, humidity, and temperature restrictions. Temperature rise and ventilation loads are computed from the following factors:

(a) Number of occupants.

(b) Heat output of the generator engine cooling system. (Cf. "Specifications for Military Standard Generators.")

(c) Heat output of the generator itself* (multiply the kilowatt capacity by 38 to obtain heat output in Btu per minute).

(d) Heat output of attached electrical equipment may be taken as the full kilowatt capacity of the generator less the power used by a separately located filter exhaust fan.

(e) Heat output of the occupants (2000 K cal/day).

(f) Heat output of a gasoline-engine-driven filter, if applicable.

Steady-state flow conditions should be used for long-duration occupancy structures requiring filter systems. Heat transfer to the structure walls, floors, or other surfaces may be neglected. Table VI, "Ventilation and Space Requirements for Protective Structures," provides the essential personnel data for design.

Upon selection of the filter unit and generator, compute and list the required supplies for the duration of occupancy. If the structure is for continuous use and the emergency equipment is to be employed for presnot use (not desirable for gasoline engines but practical for electric motors and lights), add to the amounts computed the quantity of supplies that will be necessary to provide for nonemergency operation.

* If the generator or air-filter unit is placed in an alcove which is ducted directly to the exhaust surge tank these heat sources may be eliminated.

The equipment in use and the interval between resupply are sufficient for estimating purposes.

Entrance geometry is determined primarily on the bases of intended structure employment, specific requirements set forth in the design, the directive, and the size of the equipment to be transferred after the structure has been completed. It should be determined whether the generator, filter units, or other large items of equipment are to be placed during construction (desirable when vertical entrance(s) is to be used) or are to be placed after the structure has been completed. Employment of a vertical shaft may depend solely on the desirability of removal or replacement of installed utility equipment. Consideration should be given to possible location of larger units of equipment, such as generators, at the base of shafts, connected by personnel passage to basic structure (Fig. 48).

Water supply, sanitary utilities, and emergency equipment to be placed within the structure are specified by structure utilization and availble nonemergency utilities. As is so with the fuel and lubrication storage, the supply of water, food, and other expendables, should include an allowance for periods between resupply for preshot nonemergency use of a structure. The actual design of a latrine alcove may be made at this point, depending on utilities, requirements, and utilization. Requirements for special radiation facilities such as a separate decontamination room and equipment should be noted for incorporation in the structure design.

(2) Compute the required floor area and the volume of the basic structure. The bases are the number of men, the volume required, and the area necessary for storage, equipment, and movement.

(3) Design the basic structure. Use Table X, "Protective Structures and Structural Components," and the compiled lists of building materials, prefabricated shapes, equipment, time, personnel, and the like at hand. When a choice of structure radius is available, the following consideration should be made: The volume of material to be excavated and the volume which must be replaced and compacted is a variable composed of a fixed quantity (related to the area and depth of the structure) and a term which is roughly proportional to the perimeter of the structure. Thus, a square structure requires less excavation than an elongated rectangle of the same floor area. However, the stronger structural section required for longer spans, and the inherently greater resistance to failure of shorter spans (based on the empirical analysis of nuclear weapons effects

tests) are factors which recommend an elongated short-span structure. As a rule, emergency personnel shelters, alcoves, and entrances lend themselves to use of circular steel, precast concrete pipe, and timber basic structure. Long-duration occupancy living and working stations require a greater width of floor space than storage structures. These should be made as narrow as working space and stored material dimensions permit. Where possible, a shaft should be used for storage. The advantage of reduced acceleration with depth may be noted.

(4) Design the entrance configuration and the alcoves. The entrance configuration, as determined from previous analysis, and the necessary alcoves as dictated by utilities and special requirements, are designed for compactness of the overall structural plan; functional operation of the structure's utility components; independent response of the various structural components; and aboveground considerations (for example, separation of the structure air intake and the gasoline-engine exhaust). The emergency exit should be located in an end wall and should be within a quarter of a structure span from the centerline of the basic structure.

(5) Design the end walls. The specific design of those end walls which are not integral parts of alcoves or entrances is made after the location of all of the various component structures (alcoves, entrances) is fixed. Selection is based on considerations similar to those made for the basic structure design. Independent response of the various structural components is desirable and is determined, to a large extent, by end wall design and construction.

(6) Select or design the blast resistant closures and frames.

(7) Design the supporting foundation for the door frame.

(8) Select the floor type and design and locate the storage bins. Functional placement and accessibility are critical to the location of the storage bins. Simplicity should be the criterion for selection of the type of floor to be employed in the structure, the alcoves, and the entrances.

(9) Position the remaining utilities and indicate operation or designation. These items include the following: Surge tanks, blast closure valves, air distribution ducts, antibackdraft valves, fans, engine exhaust systems, and storage bins. Locate utilities and cables entering or leaving the structure. Provide for disposal of radiation-contaminated

material such as filters and clothes. Locate and specify types of stored wrecking and entrenching equipment, electrical switchgear, electrical distribution system, and gastight seals for entrances (if required). Provide for a blast resistant antenna, exterior radiation measurement, and such other special requirements as may be necessary.

23. Design Procedure. The description and development of the directive, planning, and design procedures presented in Section V can be presented in the form of worksheets. These provide easier reference and reduce the likelihood of duplication of effort.

24. Utilization of the Design Procedure.

a. Example of Emergency Personnel Shelter. The design of an emergency personnel shelter is illustrated by example worksheets (Exhibits 1a, 1b, and 1c in the appendix). The structure is shown in Fig. 56. The design is purposely made without corrugated steel which would otherwise be the most desirable material of construction.

b. Example of Continuous Occupancy Working Station. A continuous occupancy working station is presented in which it is assumed that all materials and other facilities illustrated in the system are available. Thus, the final structure design contains most of the refinements which may be used in field construction. The worksheets of the design (Exhibits 2a, 2b, and 2c) are not completed in detail as it is assumed that almost unlimited choice is available to the engineer. The resultant structure is shown in Fig. 57.

c. Example of Drive-in Storage Structure. A storage structure is designed to illustrate the use of the massive drawbridge door. The design worksheets (Exhibits 3a, 3b, and 3c) are completed on the basis that the material and skill required for such construction are available. The structure design is shown in Fig. 58. Such a design is not desirable if a horizontal entrance can be avoided by the use of shaft entry or storage.

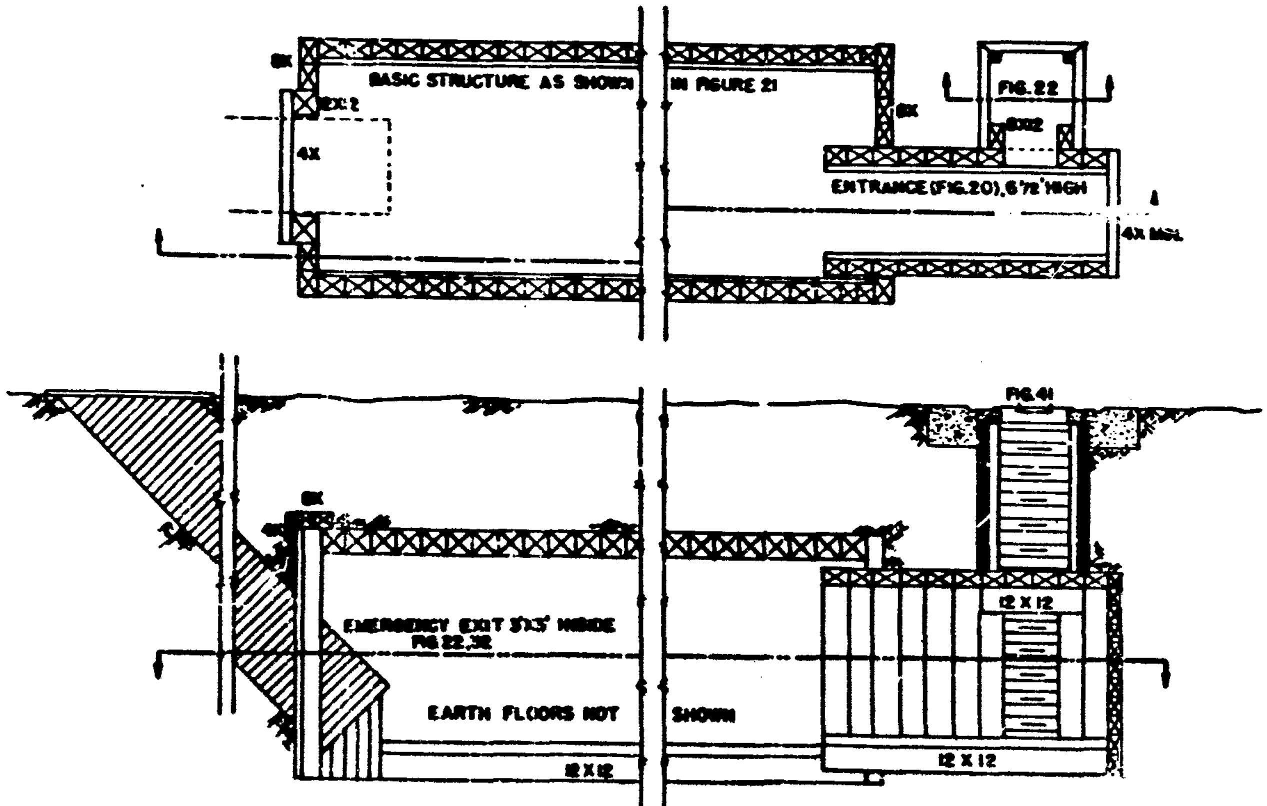


Fig. 56. Example of emergency personnel shelter.

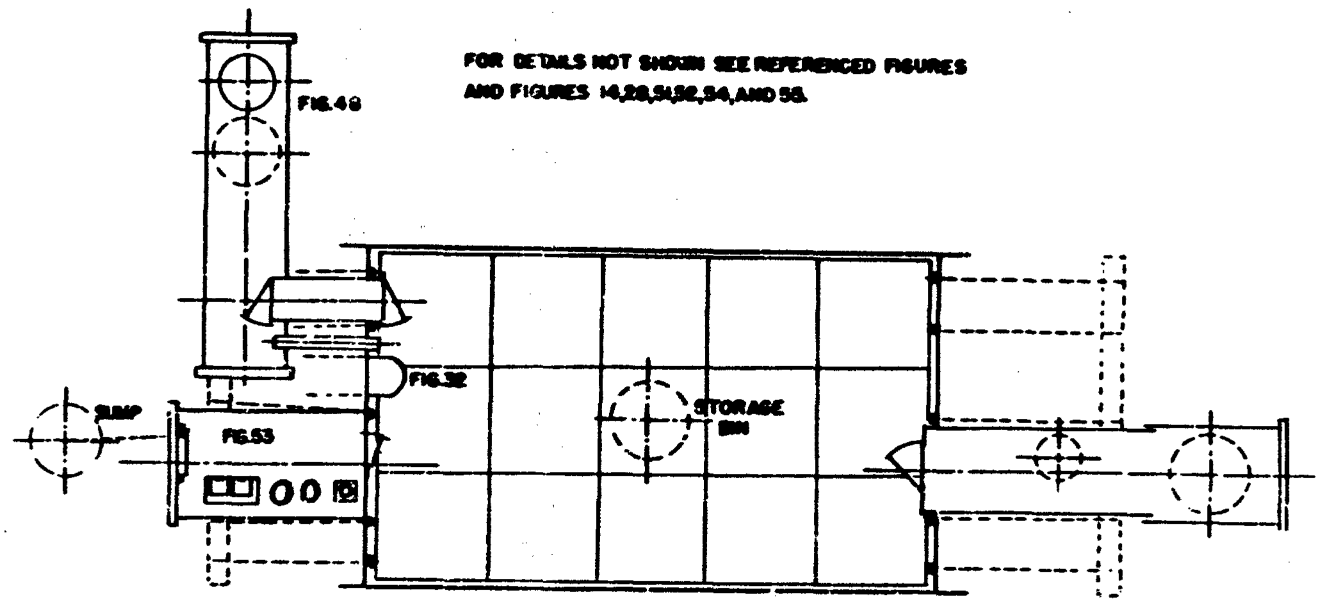


Fig. 57a. Example of continuous occupancy working station; floor plan with sections.

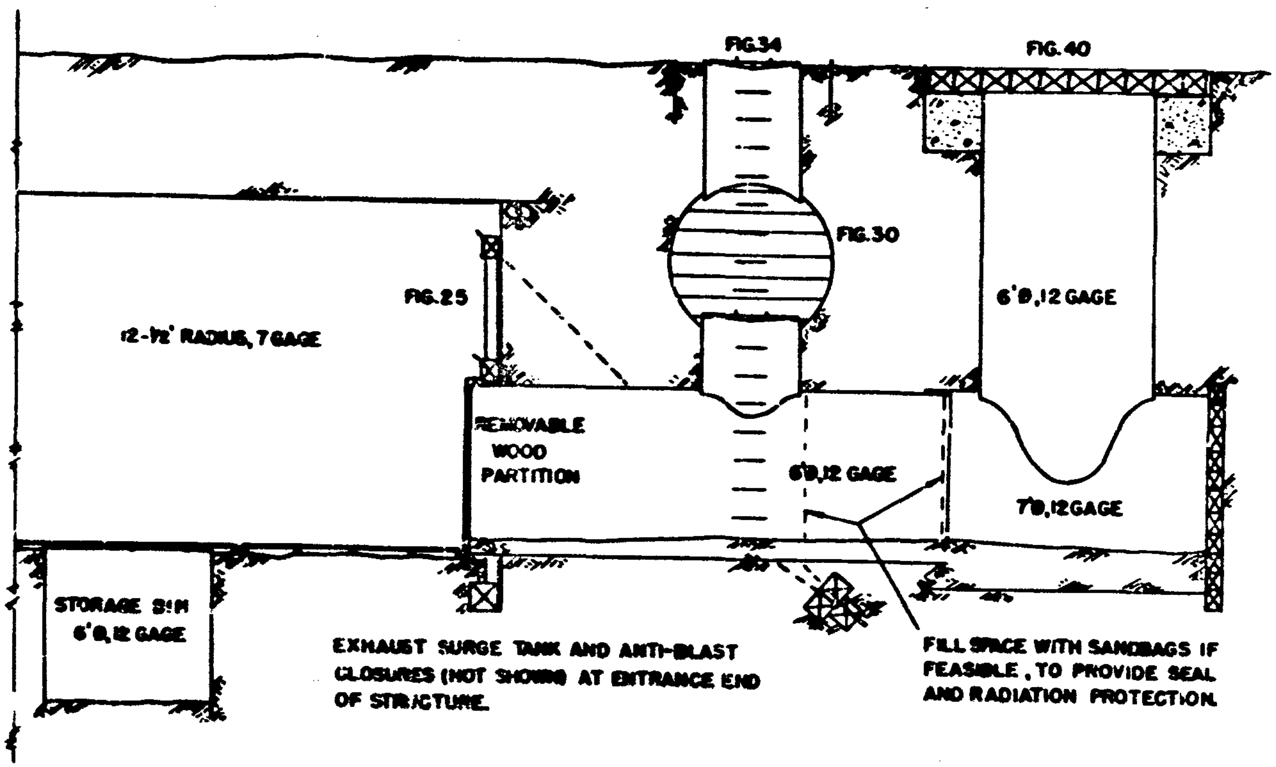


Fig. 57b. Example of continuous occupancy working station; vertical section of entrance configuration; section through centerline of each component structure.

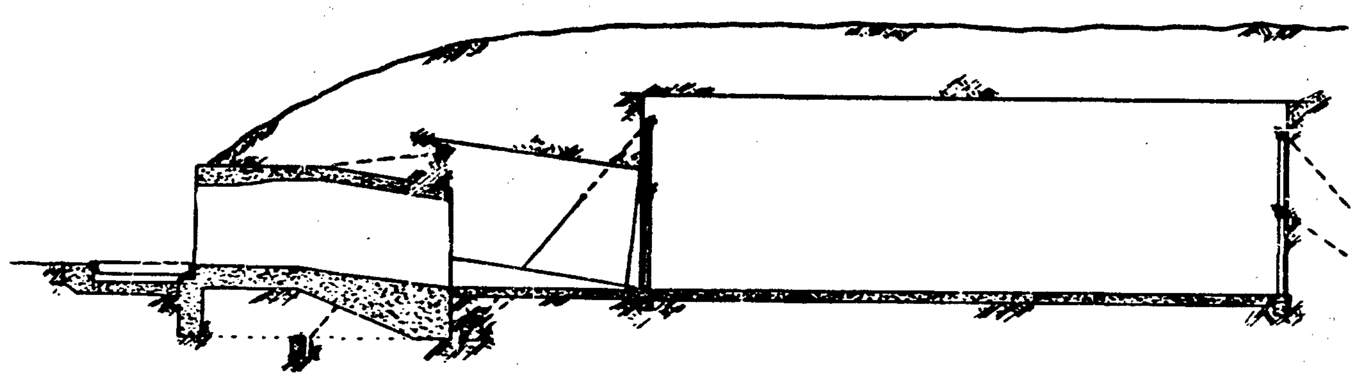


Fig. 58a. Example of drive-in storage structure: vertical section through centerline.

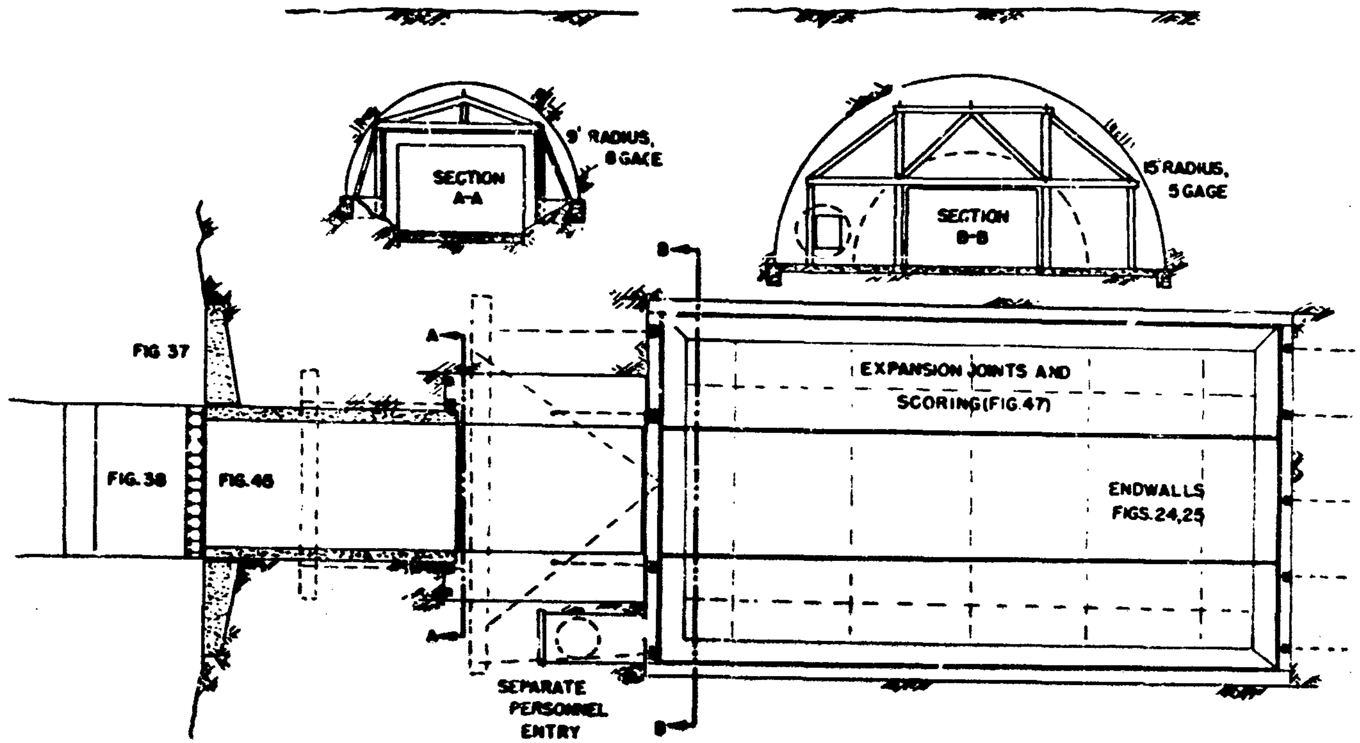


Fig. 58b. Example of drive-in storage structure; floor plan and transverse sections.

VI. CONCLUSIONS

25. Conclusions. It is concluded that:

a. Results of nuclear weapons effects tests are of sufficient scope and quality that a system of field protective construction by the use of proved structural and utility components is feasible.

b. The system of design by proved components presented here allows a field engineer not trained in nuclear weapons effects to apply the results of nuclear tests to satisfy the requirements placed upon him for protective structures.

c. Protective structures may be designed as an assembly of independent components reacting to blast or shock loadings in such a manner that the reaction of one does not weaken the resistance of another.

APPENDIX

Exhibit 1. Example of Emergency Personnel Shelter
a. Directive for Design Worksheet

1. Intended Structure Employment: Emergency personnel shelter.

   Large Equipment to Be Employed within the Structure: None

   ______________________________.

2. Post-Shot Duration of Self-Sufficient Occupancy:

   Emergency Shelter 4 hr.

   Continuous Occupancy Working or Living Station N/A days.

3. Description or Dimensions of Largest Item to Be Stored or Emplaced:

   ____ x ____ x ____ Crew-served Infantry weapons

   Other Special Entrance Considerations: Do not use air lock

4. Number of Occupants: Continuous Occupancy: 0.

   Emergency Use: 40.

   Continuous Use Emergency Augmentation: N/A.

5. Side-on Overpressure Region: 50 psi.

6. Time Duration for Which Structure Should be Designed: (6 months). ~~(permanent)~~.

7. Time Available for Construction or Date Required: N/A.

8. Conventional Weapons Protection to Be Provided: (no), ~~(yes)~~, ____.

9. Type or Designation of Unit to Perform Construction: Divisional Engineer Combat Company.

10. Equipment Augmentation Available for Construction: None

    ____

11. Specific or General Location of Structure: Not a factor

    ____

b. Predesign Data Collection Worksheet

1. Construction Materials Available:

a. Corrugated Steel: None (location).

Radius	Gage	Type	Amount Available

Straight ____ Length ____________.

b. Reinforced Concrete Pipe: None (location).

"D-Load Tests Necessary" (yes) ____.
(no) ____.

Inside Diameter	Wall Thickness	Section Length	Weight per Section	Amount

c. Concrete Construction:

(1) Cement: Yes (sacks, lb., and the like) At DESO* (location).

(2) Fine Aggregate: Division area (location).

(3) Coarse Aggregate: Division area (location).

d. Timber: DESO (location).

Size	Length	Amount	Wood Species	Quality	Condition	Preservative

e. Structural Steel: ASTM A-7 (yes), (no).

(1) Plate: DESO (location).

Dimensions	Amount
1 x 6 x 6	2
x x	

(2) Rolled Sections:

Section	Length	Amount
L 1/2 x 3 x 3	10	Unlimited

*Division Engineer Supply.

f. Utilities (check those feasible because of availability):

(1) Electric: None (battery)

Generator.

Central (blast protected).

Conventional or Public Nonemergency.

(2) Water: Stored Only.

Well Point Feasible.

Central (blast protected).

Conventional or Public Nonemergency.

(3) Sewage: Emergency Only.

Bucket-Type Latrine w/Tank or Drain Field.

Waterborne to Conventional Sewer, Nonemergency.

2. Limitations of Time, Labor, Equipment or Site:

a. Time (if covered by directive): Check types of construction made impractical because of limited time available:

In-Place Concrete.

Walk-Through Door.

Drawbridge Door.

No Limitations Because of Time.

b. Labor (if specified by directive or otherwise apparent): Check types of construction made impractical because of limited skilled labor (and time) available:

In-Place Concrete Structure.

Structural Steel.

Walk-Through Door.

Drawbridge Door.

No Limitations Because of Labor.

c. Equipment (if specified or otherwise apparent): Check those types of construction which are impractical because equipment is not available:

Larger (4 ft or more) Diameter Concrete Pipe (hoisting and hauling).

In-Place Concrete Structure (mixing).

Structural Steel (placing and welding).

Drawbridge Door (hoisting and welding).

✓ No Restrictions Because of Equipment.

d. Site Characteristics (if specified or known): Note those features of the site which may affect design or construction methods:

High Water Table.

Bed Rock.

Boulders and Cobbles in the Soil.

Soil Suitability for Backfill.

Soil Frozen to Depth ________ or Permafrost.

✓ No Restrictions Because of Site Characteristics.

c. Worksheet for Structure Design

1. Utilities (Table V):

a. Electric: Battery-powered lights to be used.

Lighting - No. of Lights______x (0.1 kw ea)__________kw

Auxiliary Electric Fans __________kw

Installed Equipment Signal, Radio, and the Like__________kw

Other - Radar, Computing, Tools, and the Like Augmented Load __________kw

Subtotal __________kw

Air Filter Electric Motor (initial estimate) __________kw

Total __________kw

Generator to Be Employed (cf. specifications for military standard generators) ________kw, __________Cooled.

Dimensions ______in. x ______in. x ______in. Weight______lb.

Mounting Type (skid) (tubular frame).

Fuel and Lubrication Storage Requirements for:

Post-Shot Occupancy before Evacuation or Resupply_______days.

Preshot Use, Time of Resupply Cycle _______days.

Total: _______days or _______hr.

Fuel:_____hr x _____gal/hr = _____gal. (gas/diesel).

Oil: _____hr x _____lb/hr = _____lb.

Volume: Fuel Storage: ________ cu. ft.

Oil Storage: ________ cu. ft.

b. Air Treatment (cf. specifications for military standard generators):

Hours of Occupancy, Gastight or with Filter __4__.

(twelve hrs or less may require no filter unit.)

(1) No Filter Unit: 4 hr Occupancy.

	Required per Person. Extrapolate Values between 3-12 Hr		No. of Personnel		Occupied Space Total
Floor Area	6	sq. ft x	40	=	240 sq. ft
Total Surface Area	32	sq. ft x	do.	=	1280 sq. ft
Volume Content	53	cu. ft x	do.	=	2120 cu. ft

(2) Mechanical Filter:

(a) Air Change Based on Oxygen Requirements:

No. of Personnel _________.

Minimum Ventilation Rate 5 cfm/Person.

Minimum Air Change 5 x ____(No. of Persons) = ____cfm.

(b) Air Change Based on Temperature:

Heat Output -

Personnel	Btu/min	No. of Personnel		Total
At Rest	7	____________	=	____Btu/min
Moderate Activity	17	____________	=	____Btu/min
Vigorous Activity	67	____________	=	____Btu/min

Generator Motor (if located where it heats basic structure air): ________ $\frac{Btu/hr}{60}$ = ____Btu/min

Electric: Lineload

Capacity of Generator: _______kw x 57 = ____Btu/min

Generator Heat Loss (if located where it heats basic air) (assuming efficiency is 70%).

Capacity of Generator: _______kw x 57 x 0.43 = ______ Btu/min

Total: _______________Btu/min

Maximum Desirable Interior Air Temperature ______ $^{\circ}F$

Maximum Probable Outside Air Temperature ______ $^{\circ}F$

ΔT = Maximum Increase Desirable in Temperature ______ $^{\circ}F$

Note: 1 Btu will raise temperature of 50 cu. ft of air 1° F.

Required cfm Air = $\frac{\text{Btu/min} \times 50}{\Delta T}$

(c) Filter Unit Selected: ______ cfm (Electric) (Gasoline).

Dimensions:

Largest Component: ____ in. x ____ in. x ____ in., Weight, ______ lb.

Overall, in Use: ____ in. x ____ in. x ____ in., Weight, ______ lb.

Storage Requirements: Fuel ______ gal, Oil ______ lb.

(If AEC-M6 with gasoline engine, use values for 1-1/2-kw generator motor.)

Spare Filters, Dimensions ______ x ______ x ______.

c. Entrance Configuration:

Required to Form an Air Lock (yes) (no).

Emergency Filled Tube Exit (yes) (no).

Radiation Decontamination in (air lock) (horizontal entry) (none).

Vertical Personnel Entry (dimension of largest item for passage)

1 ft. x 1 ft. x 1 ft.

Vertical Shaft (dimension of largest item for passage)

Not required x ______ x ______.

Horizontal Passage (dimension(s)) not critical x ______ x ______.

Blast Closures:

Walk-Through Door (dimensions) None x ______.

Double Walk-Through Door (dimensions) None x ______.

Drawbridge Door (dimensions) None x ______.

d. Water Supply:

Storage Requirements:

No. of Men 40 x No. of days 1/4 x Rate per day (1) gal = 10 gal

Plus Nonemergency Storage 0 gal

Total 10 gal

Number of 5-gal Cans 2.

Other Storage Means 0.

e. Sanitary Utilities:

Selection of Type Latrine Store Arctic-type bags.

f. Emergency Equipment (check):

Food Storage Requirement (Table IX): Type Ration: Food Packet, Individual Assault.

No. of Personnel 40 x No. of days = 40 No. of Rations. Supply two, 24-ration packages.

No. of Rations ______ x ______ cu. ft/per ration = 2.6 cu. ft.

Wrecking and Entrenching Equipment: Types Two, 6' pry bars, six shovels, two picks, two axes, wrench for closure bolt.

Communication Equipment: Types Interstructure communications, Post code outside closure.

Radiac Instruments Tactical and self-reading dosimeters.

Disposable Clothing, Type, Amounts 40 complete sets.

Decontamination Equipment, Type None.

Contaminated Clothing Disposal Bins ~~(type)~~ (no).

Tube for Surface Radiation Measurements ~~(yes)~~ (no).

Gastight Seal for Backup of Entrance (yes) ~~(no)~~.

Crew Served Weapons in Structure, Type Light Mortar, Rocket launcher

Battery-Powered Lights, Portable Radios in Structure, Types and Amounts 6 battery-powered lights.

g. Total Storage Requirements:

Fuel and Oil: Cu. ft or Bin Size 0.

Water and Food: Cu. ft or Bin Size(s) 5 cu. ft.

Emergency Equipment: Cu. ft or Bin Size 25 cu. ft.

h. Final Floor Area (volume): Floor Area As Previously Determined Amended for Equipment and Materiel Space Occupancy.

Basic Structure Only, ~~[illegible]~~ 240 sq. ft.

Volume of Structure As Previously Determined Amended for Equipment and Materiel Space Occupancy 2120 cu. ft.

2. Structure (Table X):

a. Basic Structure:

Type: Timber, shelter width (Fig. 21).

Width (radius): 8 ft. 8 in. ft (7 ft. 8 in. clear height)

Length: 32 ft.

Floor Area Approximately 275 sq. ft.

Approximate Volume 2120 cu. ft.

Foundation Elevation below Ground Surface 15 ft.

Minimum Earth Cover 5 (5) ft.

b. Entrance Configuration:

Type Vertical tube to horizontal passage (Figs. 30 and 40)

Materials of Construction Timber (Fig. 22).

Dimensions and Construction of Components

Vertical from Surface 3 - ½ ft x 3-½ ft.

Air Lock None Floor ______ End Walls ______.

Second Vertical None ______.

Horizontal Entrance Passage Timber (Fig. 20).

Floor Earth End Wall Timber.

Gastight Partition Plastic film.

Emergency Exit Either Timber 3ft x 3ft. (Fig. 22)

c. Alcoves:

Latrine - Dimensions None Partition ______.

Floor ______ Structure Type ______ End Wall ______.

Air Filter (plus generator) Dimensions None Partition ______.

Floor ______ Structure Type ______ End Wall ______.

Generator - Dimensions None Partition ______.

Floor ______ Structure Type ______ End Wall ______.

Special - Dimensions None Structure Type ______.

Partition ______ Floor ______ End Wall ______.

d. End Walls:

Type Structure supported.

Materials of Construction Timber.

Sketch Final Structure Orientation with Alcoves, Entrances, and End Walls.

e. Blast Closures and Frames:

Closure Type Designed personnel hatch.

Dimensions As shown in Fig. 41.

Frame Type Steel (Fig. 41).

Dimensions ______.

f. Door Frame-Supporting Foundation:

Type Concrete (Fig. 41).

Dimensions ______.

Sketches of Closures, Frames, and Foundations.

g. Floor:

Type in Basic Structure Earth.

Dimensions of Sectional Wood Floor ______.

Sketch Location of Storage Bins, and with Concrete Floor, the Location of Expansion Joints and Scoring.

h. Utilities Location:

Include in Sketch Locations for Utilities, Antiback Draft Valves, Emergency Equipment, and the Airflow Arrows.

Exhibit 2. Example of Continuous Occupancy Working Station
a. Directive for Design Worksheet

1. Intended Structure Employment: Continuous occupancy working station

   Large Equipment to Be Employed within the Structure: None but provide 25 ft. x 40 ft. floor area.

2. Post-Shot Duration of Self-Sufficient Occupancy:

   Emergency Shelter 4 hr.

   Continuous Occupancy Working or Living Station 10 days.

3. Description or Dimensions of Largest Item to Be Stored or Emplaced:

   4 ft. x 4 ft. x 4 ft.

   Other Special Entrance Considerations: Provide air lock.

4. Number of Occupants: Continuous Occupancy: 16.

   Emergency Use: N/A.

   Continuous Use Emergency Augmentation: 24.

5. Side-on Overpressure Region: 50 psi.

6. Time Duration for Which Structure Should be Designed: (~~months~~), (permanent).

7. Time Available for Construction or Date Required: Unlimited

8. Conventional Weapons Protection to Be Provided: (no), ~~(yes)~~, ____.

9. Type or Designation of Unit to Perform Construction: Engineer construction Company.

10. Equipment Augmentation Available for Construction: As required.

11. Specific or General Location of Structure: Not a factor.

b. Predesign Data Collection Worksheet

1. Construction Materials Available:

a. Corrugated Steel: ESP (location).

Radius	Gage	Type	Amount Available
As required			

Straight As required Length ______

b. Reinforced Concrete Pipe: ESP (location).

"D-Load Tests Necessary" ~~(yes)~~ ___.
(no) ___.

Inside Diameter	Wall Thickness	Section Length	Weight per Section	Amount
3 ft.	4 in.	3 ft.	1,600	Unlimited
8 ft.	9 in.	8	24,709	Unlimited

c. Concrete Construction:

(1) Cement: Unlimited (sacks, lb., and the like) At ESP (location).

(2) Fine Aggregate: Near (location).

(3) Coarse Aggregate: Near (location).

d. Timber: ESP (location).

Size	Length	Amount	Wood Species	Quality	Condition	Preservative
2x, 4x, 6x, 8x 10x 12x	12 ft.	Unlimited	Fir	Structural	Dry	None
12x12	24 ft	Unlimited	Pine	Structural	Dry	Creosote

e. Structural Steel: ASTM A-7 (yes), (no).

(1) Plate: ESP (location).

Dimensions	Amount
½ x 6 x L	Unlimited
__ x __ x __	

(2) Rolled Sections:

Section	Length	Amount
12 WF 65	24 ft.	Unlimited
L ½ x 3 x 3	12 ft.	Unlimited
24 WF 100	24 ft.	Unlimited

f. Utilities (check those feasible because of availability):

(1) Electric: None (battery).

Generator.

Central (blast protected).

Conventional or Public Nonemergency.

(2) Water: Stored Only.

Well Point Feasible.

Central (blast protected).

Conventional or Public Nonemergency.

(3) Sewage: Emergency Only.

Bucket-Type Latrine w/Tank or Drain Field.

Waterborne to Conventional Sewer, Nonemergency.

2. Limitations of Time, Labor, Equipment or Site:

a. Time (if covered by directive): Check types of construction made impractical because of limited time available:

In-Place Concrete.

Walk-Through Door.

Drawbridge Door.

No Limitations Because of Time.

b. Labor (if specified by directive or otherwise apparent): Check types of construction made impractical because of limited skilled labor (and time) available:

In-Place Concrete Structure.

Structural Steel.

Walk-Through Door.

Drawbridge Door.

No Limitations Because of Labor.

c. Equipment (if specified or otherwise apparent): Check those types of construction which are impractical because equipment is not available:

Larger (4 ft or more) Diameter Concrete Pipe (hoisting and hauling).

In-Place Concrete Structure (mixing).

Structural Steel (placing and welding).

Drawbridge Door (hoisting and welding).

✓ No Restrictions Because of Equipment.

d. Site Characteristics (if specified or known): Note those features of the site which may affect design or construction methods:

High Water Table.

Bed Rock.

Boulders and Cobbles in the Soil.

Soil Suitability for Backfill.

Soil Frozen to Depth ________ or Permafrost.

✓ No Restrictions Because of Site Characteristics.

c. Worksheet for Structure Design

1. Utilities (Table V):

a. Electric:

Lighting - No. of Lights 10 x (0.1 kw ea) 1 kw

Auxiliary Electric Fans ½ kw

Installed Equipment Signal, Radio, and the Like ½ kw

Other - Radar, Computing, Tools, and the Like Augmented Load ______ kw

Subtotal 2 kw

Air Filter Electric Motor (initial estimate) 2½ kw

Total 4½ kw

Generator to Be Employed (cf. specifications for military standard generators) 5 kw, Air Cooled.

Dimensions 45 in. x 29 in. x 34 in. Weight 500 lb.

Mounting Type (skid) ~~(tubular frame)~~.

Fuel and Lubrication Storage Requirements for:

Post-Shot Occupancy before Evacuation or Resupply 10 days.

Preshot Use, Time of Resupply Cycle 0 days.
Note: No preshot use because of conventional power availability.
Total: 10 days or 240 hr.

Fuel: 240 hr x 1.15 gal/hr = 276 gal. (gas/diesel).

Oil: 240 hr x .05 lb/hr = 12 lb.

Volume: Fuel Storage: 37 cu. ft. (or five, 55 gal. drums)

Oil Storage: ½ cu. ft.

b. Air Treatment (cf. specifications for military standard generators):

Hours of Occupancy, Gastight or with Filter Continuous

(twelve hrs or less may require no filter unit.)

(1) No Filter Unit: ____ hr Occupancy.

	Required per Person. Extrapolate Values between 3-12 Hr		No. of Personnel		Occupied Space Total
Floor Area	6 sq. ft	x	40	=	[illegible]2 sq. ft
Total Surface Area	30 sq. ft	x	do.	=	1200 sq. ft
Volume Content	60 cu. ft	x	do.	=	2400 cu. ft

(2) Mechanical Filter:

(a) Air Change Based on Oxygen Requirements:

No. of Personnel 40.

Minimum Ventilation Rate 5 cfm/Person.

Minimum Air Change 5 x 40 (No. of Persons) = 200 cfm.

(b) Air Change Based on Temperature:

Heat Output -

Personnel	Btu/min	No. of Personnel		Total
At Rest	7	30	=	210 Btu/min
Moderate Activity	17	10	=	170 Btu/min
Vigorous Activity	67	0	=	0 Btu/min

Generator Motor (if located where it heats basic structure air): N/A $\frac{\text{Btu/hr}}{60}$ = ____ Btu/min

Electric: Lineload

Capacity of Generator: ~~4~~ 2 kw x 57 = 114 Btu/min
Subtract 3kw for filter and exhaust fans.

Generator Heat Loss (if located where it heats basic air) (assuming efficiency is 70%).

Capacity of Generator: N/A kw x 57 x 0.43 = 0 Btu/min

Total: 500 Btu/min

Maximum Desirable Interior Air Temperature 85 °F

Maximum Probable Outside Air Temperature 60 °F

ΔT = Maximum Increase Desirable in Temperature 25 °F

Note: Assumes other than summer conditions

Note: 1 Btu will raise temperature of 50 cu. ft of air 1° F.

Required cfm Air = $\frac{\text{Btu/min} \times 50}{\Delta T} = \frac{500 \times 50}{25} = 1000$

(c) Filter Unit Selected: 1200 cfm (Electric) ~~(Gasoline)~~.

Dimensions:

Largest Component: 62 in. x 25½ in. x 25½ in., Weight, 550 lb.

Overall, in Use: 158 in. x 42 in. x 29 in., Weight, 1200 lb.

Storage Requirements: Fuel 0 gal, Oil 0 lb.

(If ADC-M6 with gasoline engine, use values for 1-1/2-kw generator motor.)

Spare Filters, Dimensions, 62 x 25 x 25.

c. Entrance Configuration:

Required to Form an Air Lock (yes) ~~(no)~~.

Emergency Filled Tube Exit (yes) ~~(no)~~.

Radiation Decontamination in ~~(air lock)~~ (horizontal entry) ~~(none)~~.

Vertical Personnel Entry (dimension of largest item for passage)

N/A x ______ x ______.

Vertical Shaft (dimension of largest item for passage)

4 ft. x 4 ft. x 4 ft.

Horizontal Passage (dimension(s)) 6 ft. Diameter x ______ x ______.

Blast Closures:

Walk-Through Door (dimensions) None x ______.

Double Walk-Through Door (dimensions) None x ______.

Drawbridge Door (dimensions) None x ______.

d. Water Supply:

Storage Requirements:

No. of Men 40 x No. of days 10 x Rate per day 1 (1) gal = 400 gal

Plus Nonemergency Storage - None required with conventional supply gal

Total 400 gal

Number of 5-gal Cans 80.

Other Storage Means ______.

e. Sanitary Utilities:

Selection of Type Latrine Conventional and [illegible] type (Fig. 53).

f. Emergency Equipment (check):

Food Storage Requirement (Table IX): Type Ration: Small Detachment [illegible].

No. of Personnel 40 x No. of days = 400 No. of Rations.

No. of Rations 400 x 0.16 cu. ft/per ration = 64 cu. ft.

Wrecking and Entrenching Equipment: Types Four, 6 ft wrecking bars, wrenches for structure bolts, ten shovels, four picks.

Communication Equipment: Types Inter-structure communications, Blast resistant antenna (Fig. 54).

Radiac Instruments Tactical and self-reading dosimeters.

Disposable Clothing, Type, Amounts 40 complete sets.

Decontamination Equipment, Type Wash stands in horizontal entry.

Contaminated Clothing Disposal Bins (yes) ~~(no)~~.

Tube for Surface Radiation Measurements (yes) (no).

Gastight Seal for Backup of Entrance (yes) (no).

Crew Served Weapons in Structure, Type None.

Battery-Powered Lights, Portable Radios in Structure, Types and Amounts As required.

g. Total Storage Requirements:

Fuel and Oil: Cu. ft or Bin Size 50 cu. ft. (approximately)

Water and Food: Cu. ft or Bin Size(s) 150 cu. ft.

Emergency Equipment: Cu. ft or Bin Size 25 cu. ft.

h. Final Floor Area (volume): Floor Area As Previously Determined Amended for Equipment and Materiel Space Occupancy.

Basic Structure Only, 1,000 sq. ft.

Volume of Structure As Previously Determined Amended for Equipment and Materiel Space Occupancy Approximately 9800 cu. ft.

2. Structure (Table X):

a. Basic Structure:

Type: Corrugated steel arch.

Width (radius): 12½ ft

Length: Total 46 ft.

Floor Area 1,000 sq. ft.

Approximate Volume 9800 cu. ft.

Foundation Elevation below Ground Surface 19 ft.

Minimum Earth Cover 5 (5) ft.

b. Entrance Configuration:

Type Vertical tube and shaft to horizontal passage (Figs. 30 and 40)

Materials of Construction Circular corrugated steel.

Dimensions and Construction of Components

Vertical from Surface 3½ ft. diameter, 8 gage

Air Lock 6 ft. diameter, 12 gage Floor Concrete End Walls Timber.

Second Vertical 3½ ft. diameter, 8 gage.

Horizontal Entrance Passage 6 ft. diameter, 12 gage.

Floor Earth End Wall Timber.

Gastight Partition Sandbag plug at shaft entry.

Emergency Exit 3 ft. diameter, 16 gage (Fig. 32)

c. Alcoves:

Latrine - Dimensions 8 ft. diameter, 12 gage Partition Endwall of structure

Floor Concrete Structure Type Corrugated steel End Wall Timber.

Air Filter (plus generator) Dimensions 6 ft. diameter, 12 gage Partition Door.

Floor Earth Structure Type Corrugated steel End Wall Timber.

Generator - Dimensions ________ Partition ________.

Floor ________ Structure Type ________ End Wall ________.

Special - Dimensions ________ Structure Type ________.

Partition ________ Floor ________ End Wall ________.

d. End Walls:

Type Deadman supported (Fig. 25).

Materials of Construction Timber frame, corrugated steel sheathing.

Sketch Final Structure Orientation with Alcoves, Entrances, and End Walls.

e. Blast Closures and Frames:

Closure Type Designed personnel hatch, timber shaft closure.

Dimensions As noted in referenced figures.

Frame Type steel (hatch), Integral (shaft).

Dimensions As noted in figures.

f. Door Frame-Supporting Foundation:

Type Concentric ring shaft and hatch.

Dimensions As noted in figures.

Sketches of Closures, Frames, and Foundations.

g. Floor:

Type in Basic Structure Sectional wood flooring.

Dimensions of Sectional Wood Floor 8 ft. x 8 ft..

Sketch Location of Storage Bins, and with Concrete Floor, the Location of Expansion Joints and Scoring.

h. Utilities Location:

Include in Sketch Locations for Utilities, Antiback Draft Valves, Emergency Equipment, and the Airflow Arrows.

Exhibit 3. Example of Drive-In Storage Structure
a. Directive for Design Worksheet

1. Intended Structure Employment: Storage, 30 ft. x 50 ft.

   Large Equipment to Be Employed within the Structure: High Priority, sensitive ordnance.

2. Post-Shot Duration of Self-Sufficient Occupancy:

   Emergency Shelter N/A hr.

   Continuous Occupancy Working or Living Station N/A days.

3. Description or Dimensions of Largest Item to Be Stored or Emplaced:

   4 ft. x 6 ft. x 15 ft.

   Other Special Entrance Considerations: Provide 10-ft.-wide entrance.

4. Number of Occupants: Continuous Occupancy: 0.

   Emergency Use: 0.

   Continuous Use Emergency Augmentation: 0.

5. Side-on Overpressure Region: 50 psi.

6. Time Duration for Which Structure Should be Designed: ~~(temporary)~~. (permanent).

7. Time Available for Construction or Date Required: Unlimited

8. Conventional Weapons Protection to Be Provided: (no), ~~(yes)~~.

9. Type or Designation of Unit to Perform Construction: Engineer Construction Battalion

10. Equipment Augmentation Available for Construction: As required

11. Specific or General Location of Structure: Not a factor

b. Predesign Data Collection Worksheet

1. Construction Materials Available:

a. Corrugated Steel: ESP (location).

Radius	Gage	Type	Amount Available
As required up	to 15 ft	radius	

Straight As required Length ________

b. Reinforced Concrete Pipe: As required (location).

"D-Load Tests Necessary" (yes) ____.
(no) ____.

Inside Diameter	Wall Thickness	Section Length	Weight per Section	Amount

c. Concrete Construction:

(1) Cement: As required (sacks, lb., and the like) At ESP (location).

(2) Fine Aggregate: Near (location).

(3) Coarse Aggregate: Near (location).

d. Timber: ESP (location).

Size	Length	Amount	Wood Species	Quality	Condition	Preservative
As required		up to	12 in.	x 12 in.		

e. Structural Steel: ASTM A-7 (yes), (no).

(1) Plate: ESP (location).

Dimensions	Amount
__ x __ x __	As required
__ x __ x __	

(2) Rolled Sections:

Section	Length	Amount
	As required	

f. Utilities (check those feasible because of availability):

(1) Electric: ✓None (battery).

Generator.

Central (blast protected).

✓Conventional or Public Nonemergency.

(2) Water: ✓Stored Only.

Well Point Feasible.

Central (blast protected).

Conventional or Public Nonemergency.

(3) Sewage: ✓Emergency Only.

Bucket-Type Latrine w/Tank or Drain Field.

Waterborne to Conventional Sewer, Nonemergency.

2. Limitations of Time, Labor, Equipment or Site:

a. Time (if covered by directive): Check types of construction made impractical because of limited time available:

In-Place Concrete.

Walk-Through Door.

Drawbridge Door.

✓No Limitations Because of Time.

b. Labor (if specified by directive or otherwise apparent): Check types of construction made impractical because of limited skilled labor (and time) available:

In-Place Concrete Structure.

Structural Steel.

Walk-Through Door.

Drawbridge Door.

✓No Limitations Because of Labor.

c. Equipment (if specified or otherwise apparent): Check those types of construction which are impractical because equipment is not available:

Larger (4 ft or more) Diameter Concrete Pipe (hoisting and hauling).

In-Place Concrete Structure (mixing).

Structural Steel (placing and welding).

Drawbridge Door (hoisting and welding).

✓ No Restrictions Because of Equipment.

d. Site Characteristics (if specified or known): Note those features of the site which may affect design or construction methods:

High Water Table.

Bed Rock.

Boulders and Cobbles in the Soil.

Soil Suitability for Backfill.

Soil Frozen to Depth ________ or Permafrost.

✓ No Restrictions Because of Site Characteristics.

c. Worksheet for Structure Design

1. Utilities (Table V):

a. Electric: Battery-powered lights to be used.

Lighting - No. of Lights______x (0.1 kw ea)__________kw

Auxiliary Electric Fans __________kw

Installed Equipment Signal, Radio, and the Like__________kw

Other - Radar, Computing, Tools, and the Like __________kw
Augmented Load

Subtotal __________kw

Air Filter Electric Motor
(initial estimate) __________kw

Total __________kw

Generator to Be Employed (cf. specifications for military standard generators) ________kw, __________Cooled.

Dimensions ______in. x ______in. x ______in. Weight______lb.

Mounting Type (skid) (tubular frame).

Fuel and Lubrication Storage Requirements for:

Post-Shot Occupancy before Evacuation or Resupply_______days.

Preshot Use, Time of Resupply Cycle _______days.

Total: _______days or _______hr.

Fuel:_____hr x _____gal/hr = _____gal. (gas/diesel).

Oil: _____hr x _____lb/hr = _____lb.

Volume: Fuel Storage: ________ cu. ft.

Oil Storage: ________ cu. ft.

b. Air Treatment (cf. specifications for military standard generators):

Hours of Occupancy, Gastight or with Filter N/A.

(twelve hrs or less may require no filter unit.)

(1) No Filter Unit: _____ hr Occupancy.

	Required per Person. Extrapolate Values between 3-12 Hr		No. of Personnel		Occupied Space Total
Floor Area	6 sq. ft	x	_____	=	_____ sq. ft
Total Surface Area	_____ sq. ft	x	do.	=	_____ sq. ft
Volume Content	_____ cu. ft	x	do.	=	_____ cu. ft

(2) Mechanical Filter: Not applicable

(a) Air Change Based on Oxygen Requirements:

No. of Personnel _________.

Minimum Ventilation Rate 5 cfm/Person.

Minimum Air Change 5 x ____(No. of Persons) = ___cfm.

(b) Air Change Based on Temperature:

Heat Output -

Personnel	Btu/min	No. of Personnel		Total
At Rest	7	_____________	=	___Btu/min
Moderate Activity	17	_____________	=	___Btu/min
Vigorous Activity	67	_____________	=	___Btu/min

Generator Motor (if located where it heats basic structure air): _______ $\frac{\text{Btu/hr}}{60}$ = ___Btu/min

Electric: Lineload

Capacity of Generator:_______kw x 57 = ___Btu/min

Generator Heat Loss (if located where it heats basic air) (assuming efficiency is 70%).

Capacity of Generator:_______kw x 57 x 0.43 = ______ Btu/min

Total:______________Btu/min

Maximum Desirable Interior Air Temperature ______ °F

Maximum Probable Outside Air Temperature ______ °F

ΔT = Maximum Increase Desirable in Temperature ______ °F

Note: 1 Btu will raise temperature of 50 cu. ft of air 1° F.

Required cfm Air = $\frac{\text{Btu/min} \times 50}{\Delta T}$

(c) Filter Unit Selected: ______ cfm (Electric) (Gasoline).

Dimensions:

Largest Component: ____ in. x ____ in. x ____ in., Weight, ____ lb.

Overall, in Use: ____ in. x ____ in. x ____ in., Weight, ____ lb.

Storage Requirements: Fuel ______ gal, Oil ______ lb.

(If ABC-[illegible] with gasoline engine, use values for 1-1/2-kw generator motor.)

Spare Filters, Dimensions ______ x ______ x ______.

e. Entrance Configuration:

Required to Form an Air Lock ~~(yes)~~ (no).

Emergency Filled Tube Exit ~~(yes)~~ (no).

Radiation Decontamination in (air lock) (horizontal entry) (none).

Vertical Personnel Entry (dimension of largest item for passage)

N/A x ______ x ______.

Vertical Shaft (dimension of largest item for passage)

None x ______ x ______.

Horizontal Passage (dimension(s)) 10 ft. wide x 7 ft. high x 19 ft. long.
(Fig. 45)

Blast Closures:

Walk-Through Door (dimensions) N/A x ______.

Double Walk-Through Door (dimensions) N/A x ______.

Drawbridge Door (dimensions) ______ x ______. (Fig. 45)

d. Water Supply:

Storage Requirements:

No. of Men None x No. of days ______ x Rate per day ___(1) gal = ______ gal

Plus Nonemergency Storage ______ gal

Total ______ gal

Number of 5-gal Cans ______.

Other Storage Means ______.

e. Sanitary Utilities:

Selection of Type Latrine None.

f. Emergency Equipment (check):

Food Storage Requirement (Table IX): Type Ration: None.

No. of Personnel ______ x No. of days = ______ No. of Rations.

No. of Rations ______ x ______ cu. ft/per ration = ______ cu. ft.

Wrecking and Entrenching Equipment: Types Wrenches fitting bolts on closures, two 6 ft. pry bars, two shovels, two picks

Communication Equipment: Types ______.

Radiac Instruments Film badges placed in structure

Disposable Clothing, Type, Amounts None.

Decontamination Equipment, Type None.

Contaminated Clothing Disposal Bins (yes) (no).

Tube for Surface Radiation Measurements ~~(yes)~~ (no).

Gastight Seal for Backup of Entrance (yes) ~~(no)~~.

Crew Served Weapons in Structure, Type None

Battery-Powered Lights, Portable Radios in Structure, Types and Amounts 6 battery-powered lights.

g. Total Storage Requirements:

Fuel and Oil: Cu. ft or Bin Size None.

Water and Food: Cu. ft or Bin Size(s) None

Emergency Equipment: Cu. ft or Bin Size Negligible.

h. Final Floor Area (volume): Floor Area As Previously Determined Amended for Equipment and Materiel Space Occupancy.

Basic Structure Only, 1500 sq. ft.

Volume of Structure As Previously Determined Amended for Equipment and Materiel Space Occupancy Not a factor cu. ft.

2. Structure (Table X):

a. Basic Structure:

Type: Corrugated steel arch.

Width (radius): 15 ft

Length: 56 ft.

Floor Area 1500 sq. ft.

Approximate Volume 17,600 cu. ft.

Foundation Elevation below Ground Surface 22 ft.

Minimum Earth Cover 5 (5) ft.

b. Entrance Configuration:

Type Horizontal entry and vertical tube to horizontal passage (Figs. 29, 38, 39, and 45)

Materials of Construction Concrete, corrugated steel.

Dimensions and Construction of Components - vertical tube to horizontal

Vertical from Surface 3½ ft. diameter, 14 gage

Air Lock None Floor ______ End Walls ______.

Second Vertical None.

Horizontal Entrance Passage 4 ft. diameter, 14 gage

Floor Earth End Wall Timber.

Gastight Partition None.

Emergency Exit None.

c. Alcoves:

Latrine - Dimensions None Partition ______.

Floor ______ Structure Type ______ End Wall ______.

Air Filter (plus generator) Dimensions None Partition ______.

Floor ______ Structure Type ______ End Wall ______.

Generator - Dimensions None Partition ______.

Floor ______ Structure Type ______ End Wall ______.

Special - Dimensions None Structure Type ______.

Partition ______ Floor ______ End Wall ______.

d. End Walls:

Type Deadman supported.

Materials of Construction Timber frame, corrugated steel sheathing.

Sketch Final Structure Orientation with Alcoves, Entrances, and End Walls.

e. Blast Closures and Frames:

Closure Type Massive Drawbridge Door (Figs. 38, 39 and 45)

Dimensions As noted in figures.

Frame Type Concrete (Fig. 45).

Dimensions As noted in figure.

f. Door Frame-Supporting Foundation:

Type Concrete (Fig. 45).

Dimensions As noted in figure.

Sketches of Closures, Frames, and Foundations.

g. Floor:

Type in Basic Structure Concrete.

Dimensions of Sectional Wood Floor N/A.

Sketch Location of Storage Bins, and with Concrete Floor, the Location of Expansion Joints and Scoring.

h. Utilities Location:

Include in Sketch Locations for Utilities, Antiback Draft Valves, Emergency Equipment, and the Airflow Arrows.

Special Category

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TITLE Protective Construction by Proved Components

DATE OF REPORT 21 Aug 61 PROJECT 8S12-95-001 CLASSIFICATION Uncl.

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U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia - PROTECTIVE CONSTRUCTION BY PROVED COMPONENTS - Capt. R. E. Sievers, Jr

Report 1689-TR, 21 Aug 61, 157 pp, 10 tables, 58 illus
DA Proj 8S12-95-001 Unclassified Report

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2. Contract - none

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